STRENGTHENING OF ROCK AGAINST SHOCK EFFECTS
DASA SUB-TASK NO. 13.192
TESTS FOR STRENGTH CHARACTERISTICS OF ROCK
PILEDRIVER PROJECT

MRD LABORATORY NO. 64/90
SEPTEMBER 1964

CORPS OF ENGINEERS
U. S. ARMY

MISSOURI RIVER DIVISION LABORATORY

OMAHA, NEBRASKA

119

PREFACE

The studies reported herein were authorized by the Chief of Engineers (ENGMC-EM) and were initially funded in FY 1964 by sub-allotment from the U. S. Army Corps of Engineers Waterways Experiment Station through the U. S. Army Corps of Engineers Ohio River Division Laboratories for research in techniques of rock strengthening.

Additional funds were received in FY 1964 from the Defense Atomic Support Agency, DASA MIPR 571-64, by sub-allotment from the U. S. Army strengthening for the PILEDRIVER project under DASA NWER Sub-Task No. 13.192 "Strengthening of Rock Against Shock Effects."

The initial emphasis of the studies conducted and reported herein are for the purpose of establishing the strength characteristics of intact and jointed rock necessary for the design, installation, and evaluation of rock strengthening systems to be incorporated in the PILEDRIVER project.

The laboratory tests were performed at the U. S. Army Corps of Engineers Missouri River Division Laboratory by members of the Physical Tests and Investigations Section under the supervision of Messrs. E. J. Deklotz and Wm. J. Heck, who also jointly prepared this report. Mr. L. A. Brown was Director of the Missouri River Division Laboratory during the conduct of the program.

Additional studies to develop strength characteristics of the fractured (jointed) rock bonded with chemical adhesives and to develop a preliminary rock bolting theory have been conducted by the U. S. Army Corps of Engineers Ohio River Division Laboratories and U. S. Army Corps of Engineers Omaha District respectively as a part of the DASA NWER Sub-Task No. 13.192 and will be presented in separate reports by those agencies.

CONTENTS

SUMMARY

The strength characteristics of the quartz monzonite has been determined by direct tensile, unconfined compression, and triaxial compression tests. The data indicate that the rock behaves elastically and retains its brittleness throughout the range of confining pressures used. In general, the rock is uniform in composition and structure, having an average bulk, dry density of 2.66 and an average porosity of 0.27 percent. Feldspar and quartz are the principal mineral constituents with a small amount of biotite making up most of the remainder of the rock.

The Mohr strength envelop for the intact rock and rock with healed joints that acted as intact rock, determined by using the average tensile strength of 1,450 psi, an average unconfined compressive strength of 30,530 psi, and average maximum principal stresses of 32,690, 36,340 and 46,050 psi at 150, 450, and 1,350 psi confining pressures respectively, is a slightly curved line from which a coefficient of internal friction angle of 56 degrees and a cohesive strength of 3,600 psi is obtained.

The angle of friction was found to be 31 degrees for the natural open joints and 28 degrees for sawed joints as determined from a plot of the points of shear and normal stresses on these pre-established planes. These values indicate that small irregularities on the joint surface have little effect on the coefficient of friction. All of the open and sawed joint surfaces showed the development of slickensides and granulation of mineral grains.

Statistical evaluation of the limited number of test results indicates that in general the rock has rather uniform strength characteristics and that the test data are reasonably consistent. The test results all fall within 95 percent Confidence Limits, assuming $\underline{t}$ distribution and using Student's $\underline{t}$ values. Coefficient of variation ranged from 3.3 percent for unconfined compression tests to 28.2 percent for the tensile strength tests. Values of 10.8 to 16.8 percent were obtained for the intact rock triaxial compression tests.

TESTS FOR STRENGTH CHARACTERISTICS OF ROCK

PILEDRIVER PROJECT

INTRODUCTION

1. This report presents results of tests for shear, compressive, and tensile strength characteristics of rock of the type which will be encountered and subject to rock strengthening techniques and evaluation as part of Piledriver Project. Triaxial compression tests were made of intact rock and of rock having natural healed or open joints, and joints smoothly sawed in the laboratory. Unconfined compression and direct tension tests were made of intact rock and of rock containing natural healed joints. Certain testing and instrumentation techniques were developed and are described in detail where it is considered the information may be of value in future work of a similar nature.

ROCK IDENTIFICATION

2. Sections of the 2 3/8 inch diameter rock core, from Exploratory Drill Hole U15O1-U1 at the project site were submitted for test. Top elevation of hole is 4254.7 feet. The hole is an inclined boring at a downward angle of 21° from horizontal. Throughout this report all depths are inclined depths of core along the boring. Only that portion of rock core which lies in the quartz monzonite was submitted for test. The quartz monzonite is generally a light gray, dense, porphyritic rock with a fine to medium-grained groundmass. Orthoclase and plagioclase feldspars with quartz are the most abundant minerals; however, a small but varying amount of biotite mica occurs as scattered flakes or clusters. Occasionally large, pink crystals of feldspar up to 2 1/2-inches in length are present. Very little alteration and weathering was noted in the core specimens tested. Most of the healed joints observed in the rock are well cemented with quartz and feldspar along with a small amount of calcite. Pyrite was also a common mineral in some of the healed joints. A few of the cores were partially healed with a water soluble mineral which dissolved when the cores were soaked prior to test; consequently these cores separated at the joint and had to be tested as open joint rock specimens. The natural open joints were generally free of mineral deposits or rock dust and their surfaces, although rough, were essentially planar.

TEST PROGRAM

3. Core specimens were selected for test as follows:

Triaxial Compression Test Specimens

Condition of Rock Core	Core No.	Confining Pressure, Psi	Angle of Joint from Horizontal, degrees
Intact Rock	37, 133, 144	150	-
	40, 46, 69	450	-
	28, 83, 136	1350	-
Natural Healed Joints	130, 105, 142, 143	150	41, 55, 60, 62 & 69
	131, 151, 138, 159	450	44, 55, 61, 64
	155, 134, 153	1350	51, 57, 64
Natural Open Joints	120, 127, 158, 108, 125	150	38, 54, 59, 62, 66
	169, 107, 164	450	44, 62, 66
	112	1350	50
	159	3000	64
Sawed Joints	23	150	55
	22, 11,	450	45, 62
	12, 18, 27	1350	45, 55, 62
	128, 129, 35	3000	45, 55, 62
Unconfined Compression Test Specimens			
Intact Rock	39, 86, 132	-	-
Natural Healed Joints	150, 137	-	56, 63
Direct Tension Test Specimens			
Intact Rock	9, 88, 126	-	-
Natural Healed Joints	30, 43, 145, 54	-	54, 65 & 90, 66 & 90, 90
Cyclic Loading in Unconfined Compression			
Intact Rock	47	-	-

Pieces of core cut from the ends of the several strength test specimens identified above were tested for bulk saturated surface-dry specific gravity, bulk dry density, and porosity.

4. The stress-strain data presented graphically in this report can be made available in tabulated form upon request.

PROCEDURE AND RESULTS

Specific Gravity, Density, and Porosity

Procedure

5. In the preparation of the strength test specimens, the longest end piece cut from each strength test core was squared on both ends and used in the determination of bulk saturated surface-dry specific gravity, measured bulk dry density, and porosity. Lengths of these end pieces varied from 1.16 to 4.35 inches. According to the procedure provided in the authorizing test requests, each specimen was measured for length at quarter points and for diameter at third points about the circumference and the volume computed from these measurements. The specimens were permitted to absorb water at room temperature by immersion within a pressure vessel for 1/2-hour at 1200 psi pressure and, upon completion of the saturation period, were individually weighed in water, surface dried, and again weighed in air. The oven dry weight was determined after drying for 72 hours at 230 F. The several parameters were computed as follows:

a. Specific gravity, bulk saturated surface-dry

$$g = \frac{B}{B-D}$$

where -

g = Specific gravity, bulk saturated surface-dry

B = Weight in grams of saturated surface-dry specimen in air

D = Weight in grams of saturated specimen in water (saturated by immersion in water for 1/2-hour under 1200 psi pressure)

b. Measured bulk dry density

$$d = \frac{A}{V_1}$$

where -

d = Measured bulk dry density

A = Weight in grams of oven dried specimen in air

V_1 = Volume in cubic centimeters of specimen calculated from measurements.

c. Porosity

$$p = \frac{V_2}{V_3} \times 100$$

where -

V_2 = Void volume, B-A

V_3 = Solid volume, V_1-V_2

Results

6. Results of these tests are presented in Table 1, and indicate that the quartz monzonite is very uniform in composition and structure.

Triaxial Compression Tests

Procedure

7. Tests in triaxial compression were made to determine the shear strength of the several conditions of rock. All cores were cut to an L/D ratio of 2, ends ground and lapped, and immersed for 72 hours in water at room temperature before testing. Particular care was taken in cutting and finishing the ends of the cores to assure that they were approximately normal to the axis and that essentially parallel, flat, smooth end surfaces were obtained. Final finishing was accomplished by hand lapping on a glass plate with No. 600 carborundum compound. The sawed joints were produced with a diamond saw at the preselected angles and rough ground with No. 240 carborundum to remove the saw grooves.

8. The triaxial compression testing was conducted with the apparatus shown in Plate 1 in which confining pressures up to 10,000 psi can be maintained while axial loads up to 400,000 pounds are applied with a universal hydraulic testing machine. Axial strain was measured by a 1/10,000-inch dial gage. Corrections were made for the deformation of the hardened steel parts (Rockwell C 58 or harder), in order to determine the true strain of the rock specimen during test. All of the core specimens were surface dried after the 72-hour immersion period. A thin (15 mil) sheet of vinyl plastic was placed around the core and the top and bottom steel platens to prevent punctures at the interface. The assembly was then covered with a thick rubber membrane made from a section of motor bike inner tube and sealed with rubber O rings to prevent oil from entering the specimen.

9. After the triaxial apparatus was completely assembled, anti-foaming hydraulic oil was pumped into the chamber until it drained from the overflow tube and air bubbles ceased to rise. The confining pressure was raised to the desired value and maintained constant throughout the test by manual operation of the screw piston device attached to the base of the apparatus. Axial loads were applied to produce, as nearly as possible, a rate of strain of 1/1000 inch per minute in the specimen until failure occurred. Pre-established joint or failure planes were subjected to multi-stage triaxial tests in which, after failure, the confining pressure was raised to the next higher preselected value and the test continued. In some cases this procedure was repeated a number of times.

Results

10. Stress-strain curves and companion Mohr diagrams for the several test conditions are shown in Figures 1 through 78 with a brief description of each core specimen and a diagram of the manner of failure. Photographs of cores showing typical failure planes after test are presented in Plates 2 and 3.

11. The modulus of elasticity, E, is determined as the slope of the straight line portion of the stress-strain curve and the value is shown with each curve. The average values of E of intact rock cores and of cores with healed joints which failed as intact rock are:

Confining pressure, psi,	150	450	1350
Modulus of elasticity, 10^6 psi,	11.75	11.74	11.38

12. The E values for the unconfined compression and tensile test specimens determined by strain gage measurements are 10.46×10^6 and 8.48×10^6 psi, respectively.

13. A statistical summary of the triaxial compression test results for the average maximum principal stresses of five specimens, three of intact rock and two of well-healed jointed rock, at each of the selected confining pressures is as follows:

Confining pressure, psi,	150	450	1,350
Maximum principal stress, psi,	32,690	36,340	46,050
Standard deviation, psi,	5,210	3,910	7,750
Coefficient of variation, percent,	15.9	10.8	16.8
95 percent Confidence Limits, Student's *t* distribution, psi, *	19,240 to 47,140	25,490 to 47,190	24,540 to 67,560

* U. S. Army Engineer Waterways Experiment Station, CE, Basic Statistical Definitions and Procedures. Miscellaneous Report No. 2-250 (Vicksburg, Miss., January 1958).

Unconfined Compression Tests

Procedure

14. Specimens for unconfined compressive strength tests were cut, prepared, and immersed in water prior to test in the same manner as the triaxial compression test specimens described in paragraph 7 above. Axial and diametric strains were measured by use of Type A-1 SR-4 strain gages cemented to the specimens with Eastman 910 cement. Three axial gages were equally spaced around the specimen at the center of its height, and three diametric gages were similarly located around the diameter. Specimens were loaded through a high strength steel spherical head and solid pedestal of Rockwell Hardness C 58, at a rate of 50 psi/sec. The bearing face of the spherical head and solid pedestal is 2.42 inches in diameter and is ground flat to 0.0005-in. No capping material was used on the test specimens. Plate 4 is a photograph of one of the test specimens in the testing machine immediately prior to loading.

Results

15. Results of these tests are graphically presented in Figures 79 through 83. Poisson's Ratio was computed using values taken from the curves for diametric and axial strain. Ignoring infinitesimals of the second order it can be shown that the volumetric strain is equal to the axial strain plus 2 times the diametric strain. The stress-volumetric strain curve appears to be of interest as it seems to provide a means for determining the "yield point" of the rock which can be defined as that point on the curve at which the slope of the tangent changes sign. The curve seems to indicate further a consolidation of particles as the load increases up to this point; beyond this point the rock structure begins to disrupt and tear apart. For the 5 specimens tested using strain gage instrumentation, it will be observed that this point ranges between approximately 20,000 and 25,000 psi. Two additional specimens, Core Nos. 32 and 84, were tested for compressive strength with no strain gage instrumentation. These cores showed ultimate strengths of 29,480 and 32,200 psi, respectively. The results of all seven tests are summarized as follows:

Maximum Compressive Strength, Core No. 84, psi,	32,200
Minimum Compressive Strength, Core No. 32, psi,	28,770
Average Compressive Strength, psi,	30,530
Standard Deviation, psi,	1,162
Coefficient of Variation, percent,	3.3
95 percent Confidence Limits, Student's *t* distribution, psi,	27,690 to 33,370

Direct Tension Tests

Procedure

16. All direct tension test specimens were immersed in water for 72 hours at room temperature prior to test. Generally the test specimens were cut to an L/D ratio of 2 and cemented into metal end caps using an epoxy resin material identified as Plastic Steel, Devcon A - Putty Type, produced by the Devcon Corporation, Danvers, Mass. After allowing to harden for 24 hours, the assembly, with SR-4 strain gages attached in the same configuration as for the unconfined compression test specimens, is suspended by means of heavy duty roller chain in the testing machine and load applied to failure. Plate 5 is a photograph of a specimen immediately prior to test. The upper and lower roller chain are at right angles to each other in order to reduce eccentricity and bending in the specimen.

Results

17. Stress-strain curves are shown in Figures 84 through 90. Initially the tests were conducted using full cross-section specimens; however, with the development of failures in the cap (Core No. 54, Figure 90) which were considered to be a manifestation of end restraint, it was decided to test reduced section specimens. The reduced sections were cut by means of a carbide tipped tool in a machine lathe operating at slow speed with a minimum amount of water. Improvement was shown in type of break by this method but, under this condition, one end break (Core No. 126, Figure 86) did occur. One specimen, Core No. 51, was tested for tensile strength with no strain gage instrumentation and showed an ultimate tensile strength of 2,353 psi. The results of all eight tests are summarized as follows:

Maximum Tensile Strength, Core No. 51, psi,	2,353
Minimum Tensile Strength, Core No. 145, psi,	1,026
Average Tensile Strength, psi,	1,452
Standard Deviation, psi,	410
Coefficient of Variation, percent,	28.2
95 percent Confidence Limits, Student's *t* distribution, psi,	482 to 2,422

18. In view of the values obtained for compressive strength, the difficulties encountered in developing a truly direct tensile load on the specimens, and the strength envelops to be discussed later, it is considered that the strength shown by Core No. 51 may most nearly represent the true tensile strength of the rock. The strength of the remaining 7 cores all appear rather low.

Cyclic Loading in Unconfined Compression

Procedure

19. One specimen, Core No. 47, was cyclic loaded to failure in unconfined compression. The specimen was prepared for test in the same manner as described for the conventional unconfined compression test specimens. The first three loadings were to nominally 20,000 psi. Subsequent duplicate loadings were increased in approximately 2,000 psi increments beyond the original 20,000 psi loadings and failure occurred at the beginning of load release during the eleventh cycle. Strain readings were taken upon load release as well as during load application.

Results

20. Stress-strain data are tabulated in Tables 2 and 3. Figures 91 and 92 are stress-strain curves for a representative selection of the several loadings. It is not entirely clear why the axial strain values show a strain reversal (tension) upon load release unless perhaps this is a manifestation of strain gage slippage. If this is true, a change to epoxy resin type cement might correct this condition. Further investigation in this area seems to be indicated.

GENERAL DISCUSSION OF TEST RESULTS

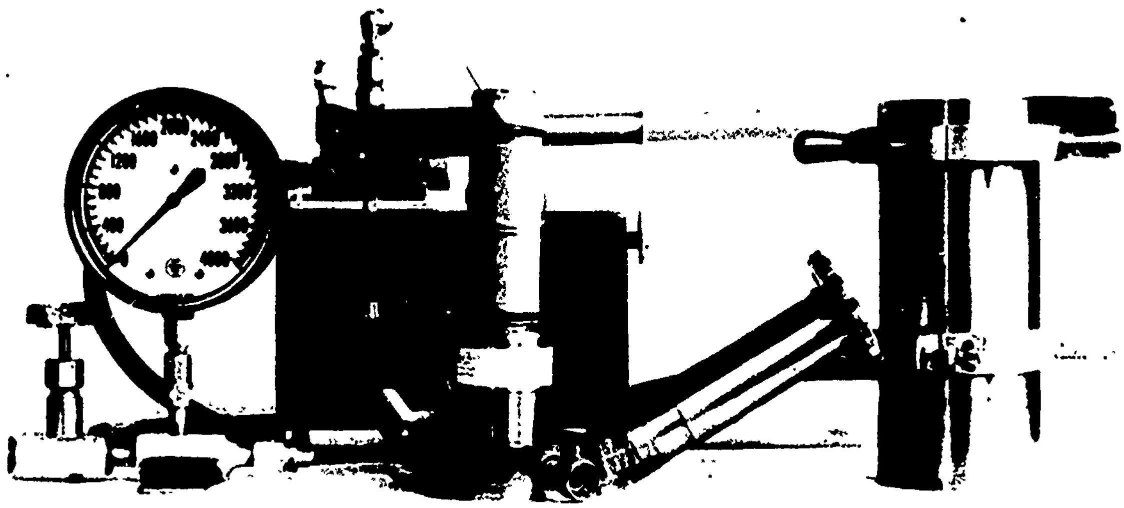
21. When the shear strengths on a pre-established plane such as an open or sawed joint are plotted as in Figure 93, a strength envelop of best fit of the points is obtained from which the coefficient of friction angle is determined. It is interesting to note that the angle of friction of sawed and natural joints are very similar (28 to 31 degrees), being only 3 degrees apart. The points plotted represent points of failure at all stages of confining pressure. Generally, there appears to be little difference between the angles of friction obtained from plots of the first stage and subsequent stages. Furthermore the coefficient of friction is fairly constant for the range of joint angles tested. This would indicate that the coefficient of friction is reasonably constant for this rock and unless the joint plane surfaces are extremely nonplanar small surface irregularities have very little effect in increasing the angle of friction. Small slickensides and granulation of mineral grains were developed on the joint plane surfaces.

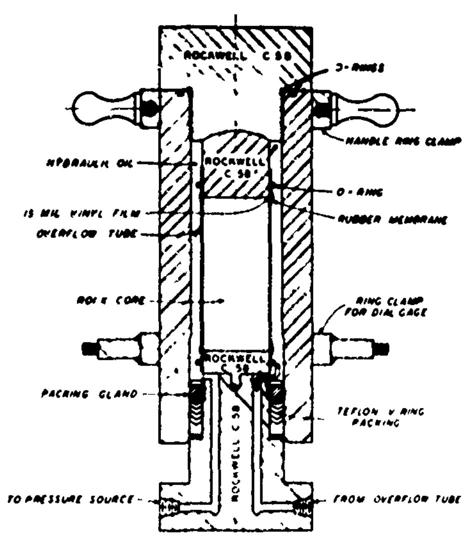
22. The Mohr envelop for the intact rock was determined from the average strengths of a group of 5 cores for each confining pressure and includes the averages of those tested in tension and unconfined compression. Since the rock cores with well-healed joints behaved as intact rock when tested in triaxial compression,

their results have been included with this group. Joints healed with quartz and feldspar appeared to be as strong as the intact rock, while those filled primarily with pyrite are somewhat weaker. For the three confining pressures used the strength envelop shows a coefficient of internal friction angle of about 56 degrees and a cohesive strength of about 3,600 psi. The envelop tends to be practically a straight line but becomes slightly curved when fitted to the unconfined compression and tensile strength values. A straight line projection in this area of the curve indicates a tensile strength of around 2,500 psi. This more nearly checks the value of 2,353 psi shown by Core No. 51.

23. Generally the observed shear angles approach those determined from the formula $45^{\circ} + \frac{\phi}{2}$ (73 degrees) with only a few degrees difference. In most cases, the measured shear plane angles of the unconfined compression tests show the greatest variation, about 7 degrees less than the computed values. It was only with the confining pressure of 1,350 psi that the core specimens tended to shear along a single plane without vertical tension fractures. For the most part, the test results appear to fit Mohr's criterion quite well.

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA





TRIAXIAL CELL

TRIAXIAL TEST APPARATUS

PLATE 1

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

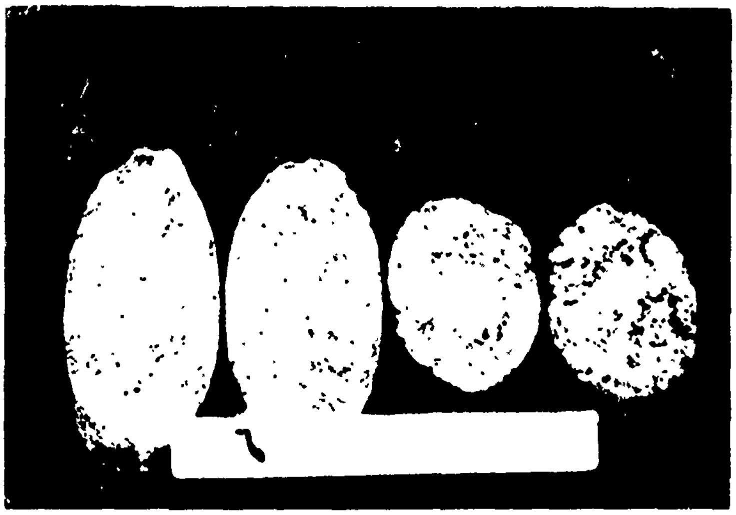
Intact Rock

Natural Healed Joints

TYPICAL ROCK CORES AFTER TEST

PLATE 2

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

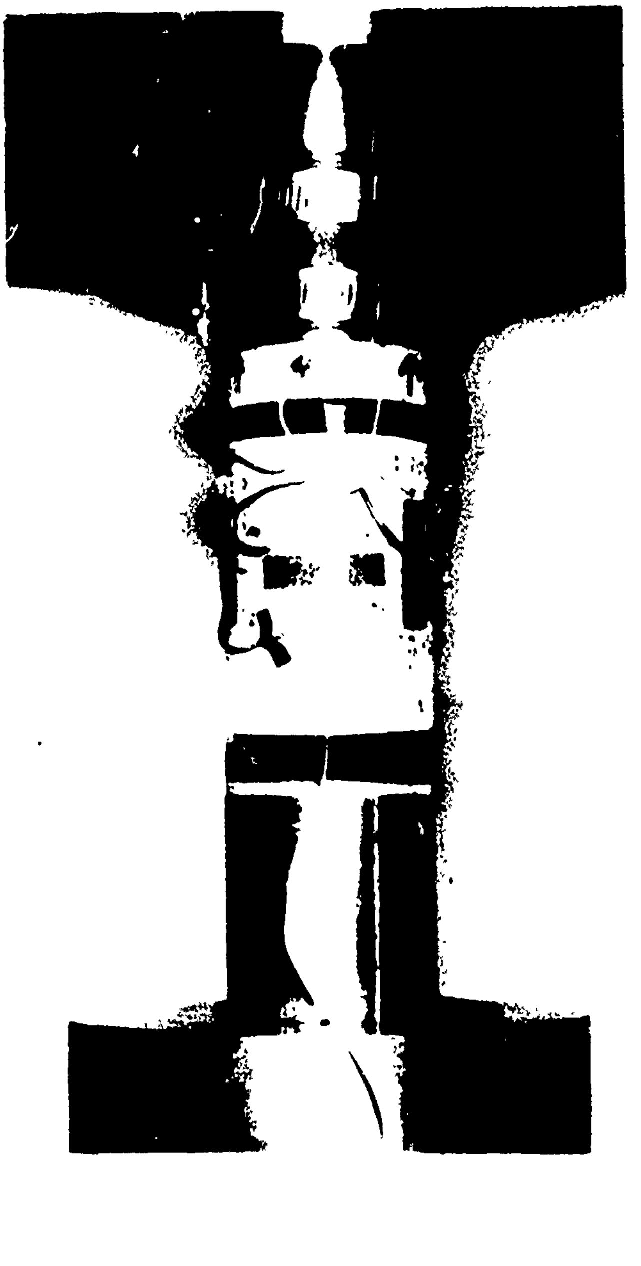


Natural Open Joints

Sawed Joints

TYPICAL ROCK CORES AFTER TEST

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA



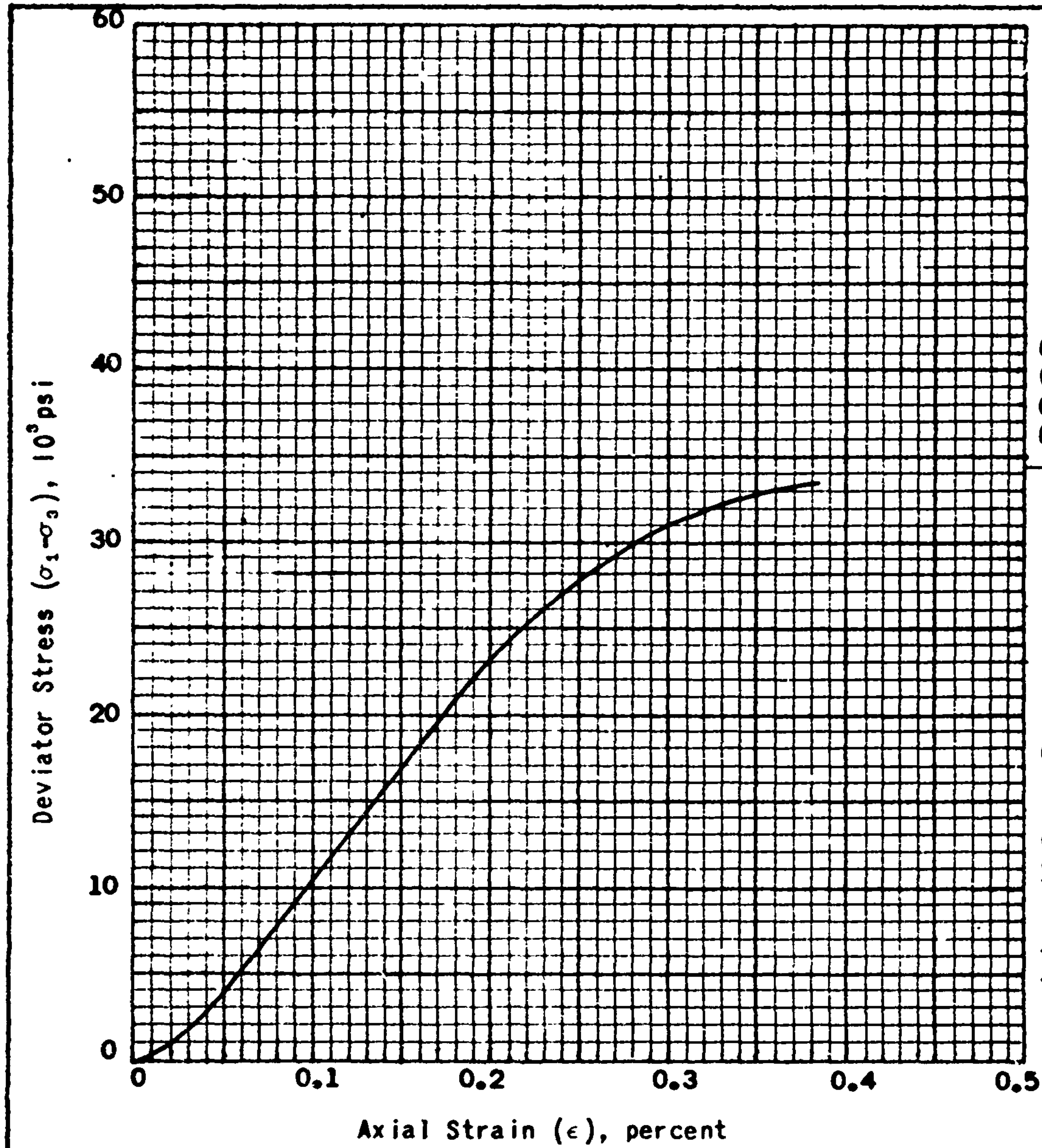
UNCONFINED COMPRESSION TEST ASSEMBLY

PLATE 4

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

DIRECT TENSION TEST ASSEMBLY

PLATE 5



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 37, MRD Lab. No. 64/90
Core Depth 570.1-580.4 feet
Core Diam. 2.382 in., Core Ht. 4.46 in.
Core Weight, SSD, 930.9 gm.

Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi,
① 150	13.00
②	
③	
④	

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, fine to medium-grained, with a few large (1-in.) crystals of pink feldspar.

In triaxial compression, the core broke partially in shear, but mostly with vertical tension fractures.

MRD FORM 1 APR 64 737

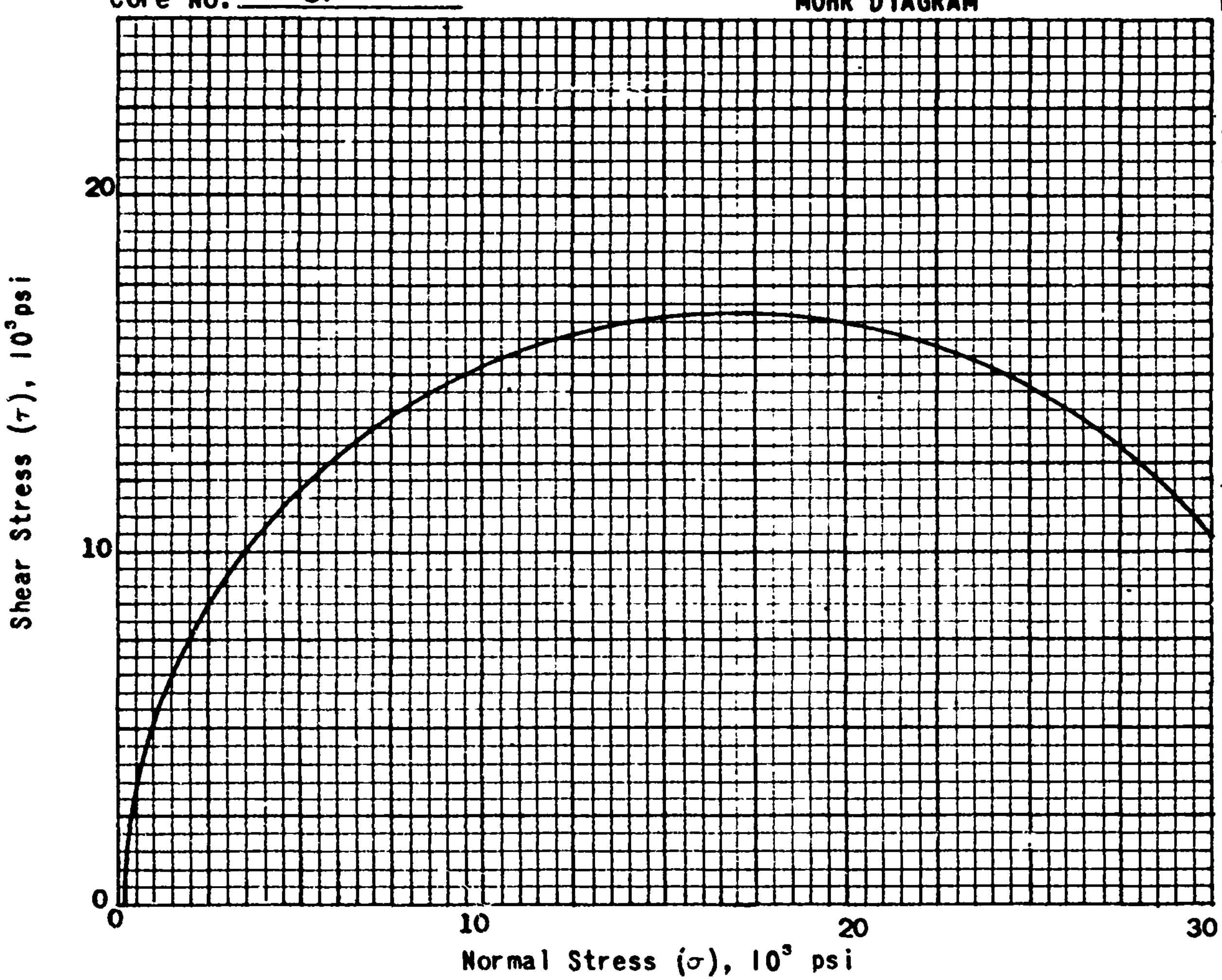
FIGURE 1

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 37

MOHR DIAGRAM

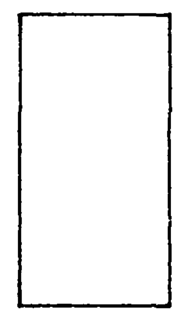


MRD Lab. No. 64/90

PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Plane	Normal Stress (σ), psi Failure Plane
150	33,650	-	-

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Plane	Shear Stress (τ), psi Failure Plane
150	33,650	-	-

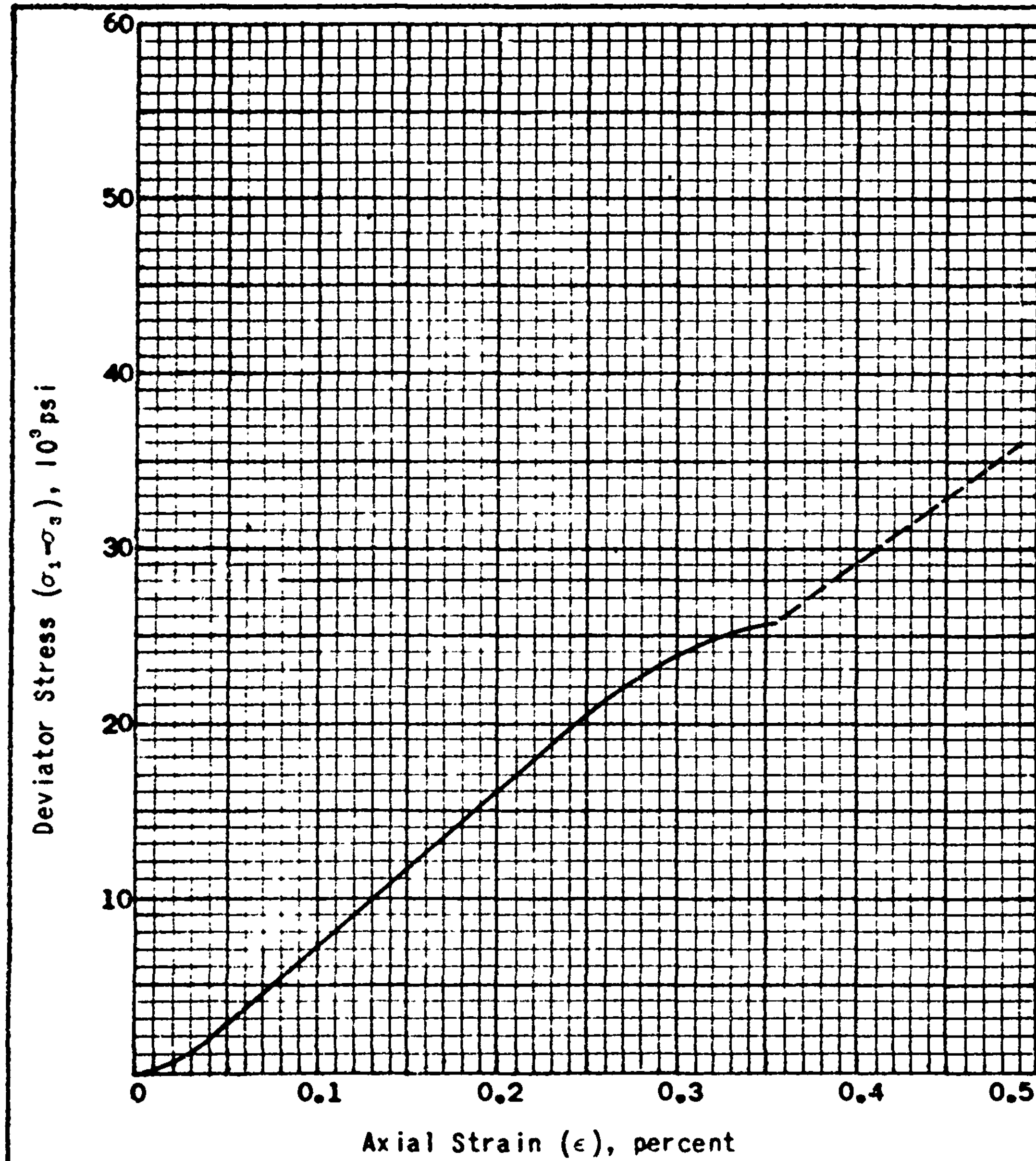


Plane

Failure Plane

MRD FORM
1 APR 64 738

FIGURE 2



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 133, MRD Lab. No. 64/90
Core Depth 723.5-724.1 feet
Core Diam. 2.411 in., Core Ht. 4.82 in.
Core Weight, SSD, 964.8 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi,
①	150	8.87
②		
③		
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with a medium-grained groundmass. A few feldspar phenocrysts of 3/4-in. length occur in the end sections of the core specimen.

In triaxial compression, the core broke partially in shear, but mostly with vertical tension fractures. The dashed portion of the stress-strain curve is shown to indicate that the strength of the rock exceeded the yield strength of the steel used in the triaxial apparatus.

MRD FORM
1 APR 64 737

FIGURE 3

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

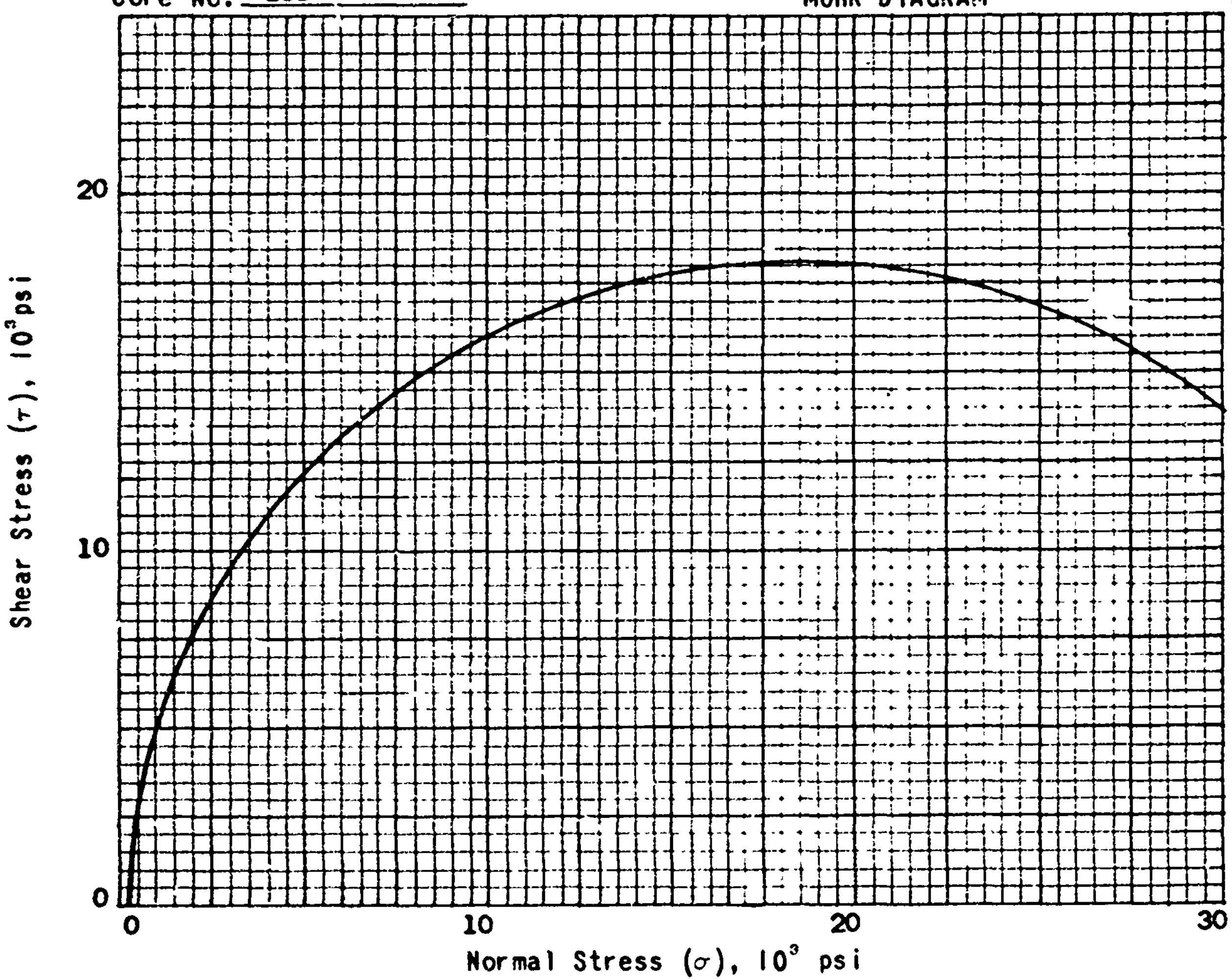
TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 133

MOHR DIAGRAM

MRD Lab. No. 64/90

PILEDRIVER



Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Plane	Normal Stress (σ), psi Failure Plane
150	36,320	-	-

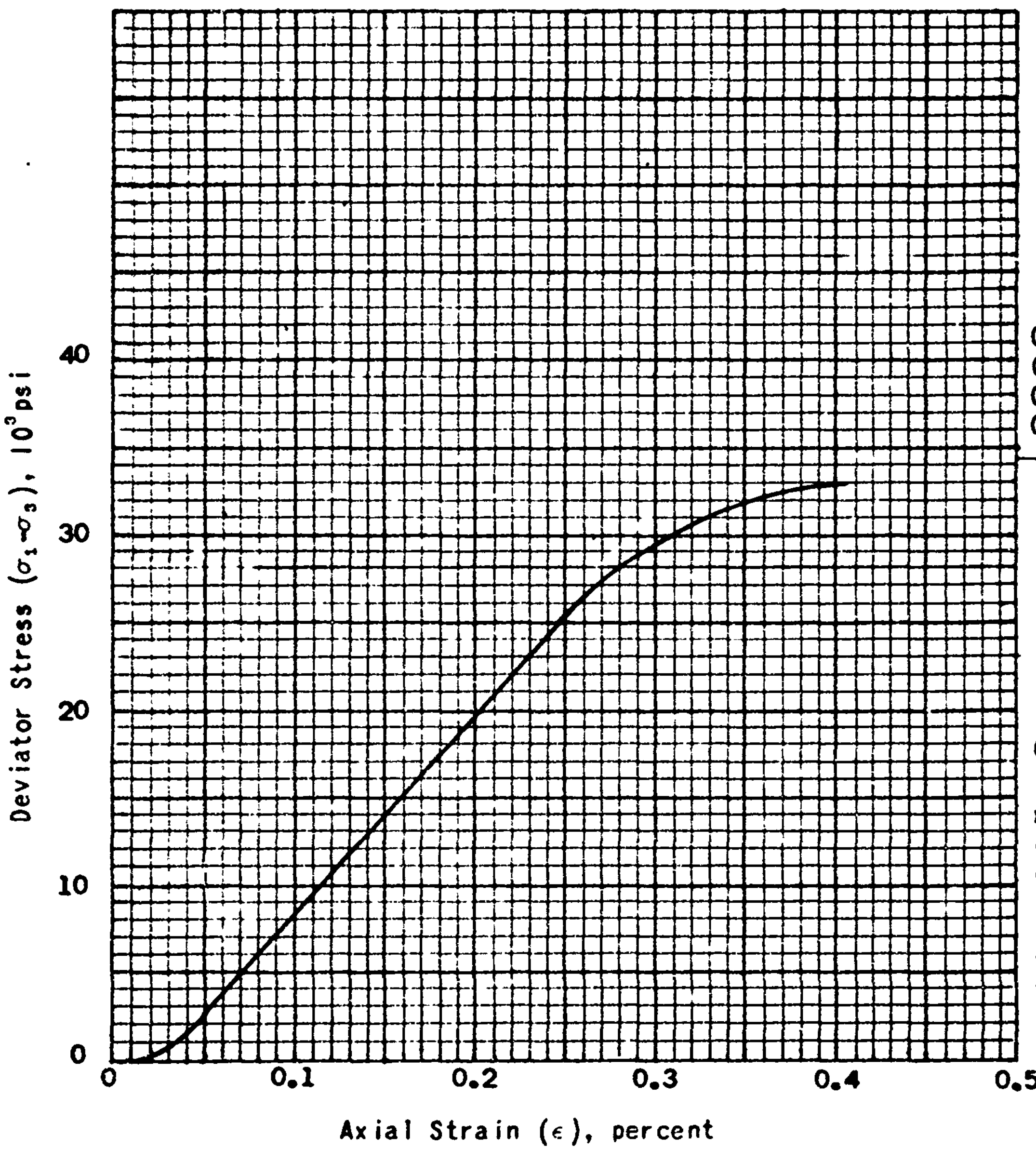
Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Plane	Shear Stress (τ), psi Failure Plane
150	36,320	-	-

Plane

Failure Plane

MRD FORM 1 APR 64 738

FIGURE 4



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 144, MRD Lab. No. 64/90
Core Depth 546.2-547.4 feet
Core Diam. 2.398 in., Core Ht. 4.76 in.
Core Weight, SSD, 935.5 gm.

Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi,
① 150	11.25
②	
③	
④	

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. A few feldspar phenocrysts of ½-in. length occur in the end sections of the core specimen.

In triaxial compression, the core broke partially in shear, but mostly with vertical tension fractures.

MRD FORM 1 APR 64 737

FIGURE 5

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

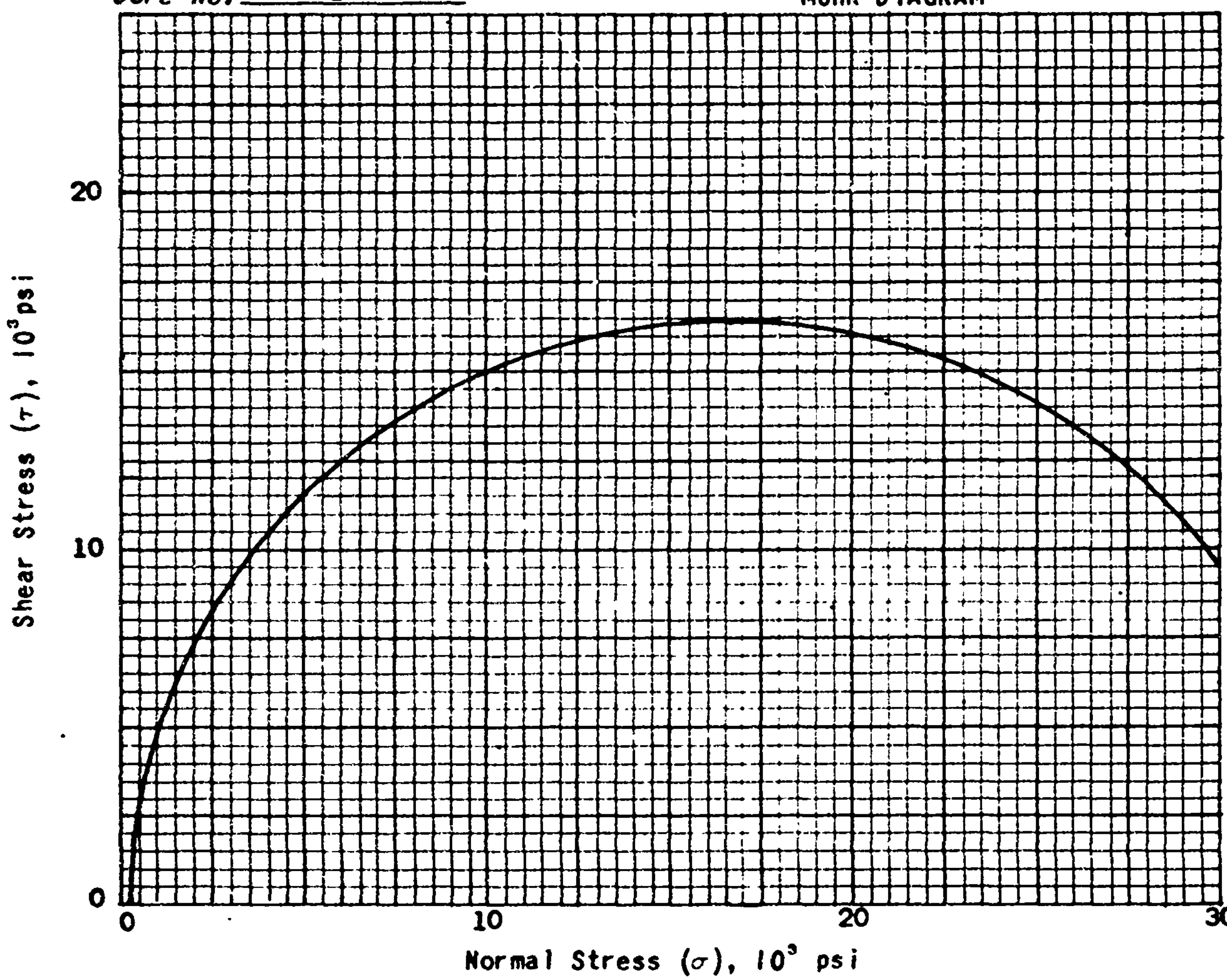
TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 144

MRD Lab. No. 64/90

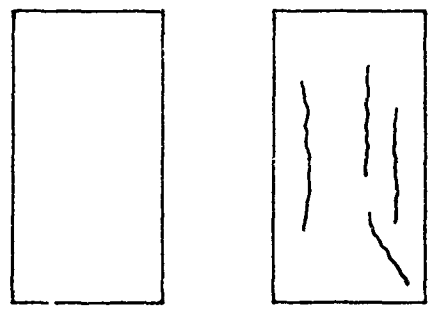
PILEDRIVER

MOHR DIAGRAM



Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Plane	Normal Stress (σ), psi Failure Plane
150	32,920	-	-

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Plane	Shear Stress (τ), psi Failure Plane
150	32,920	-	-

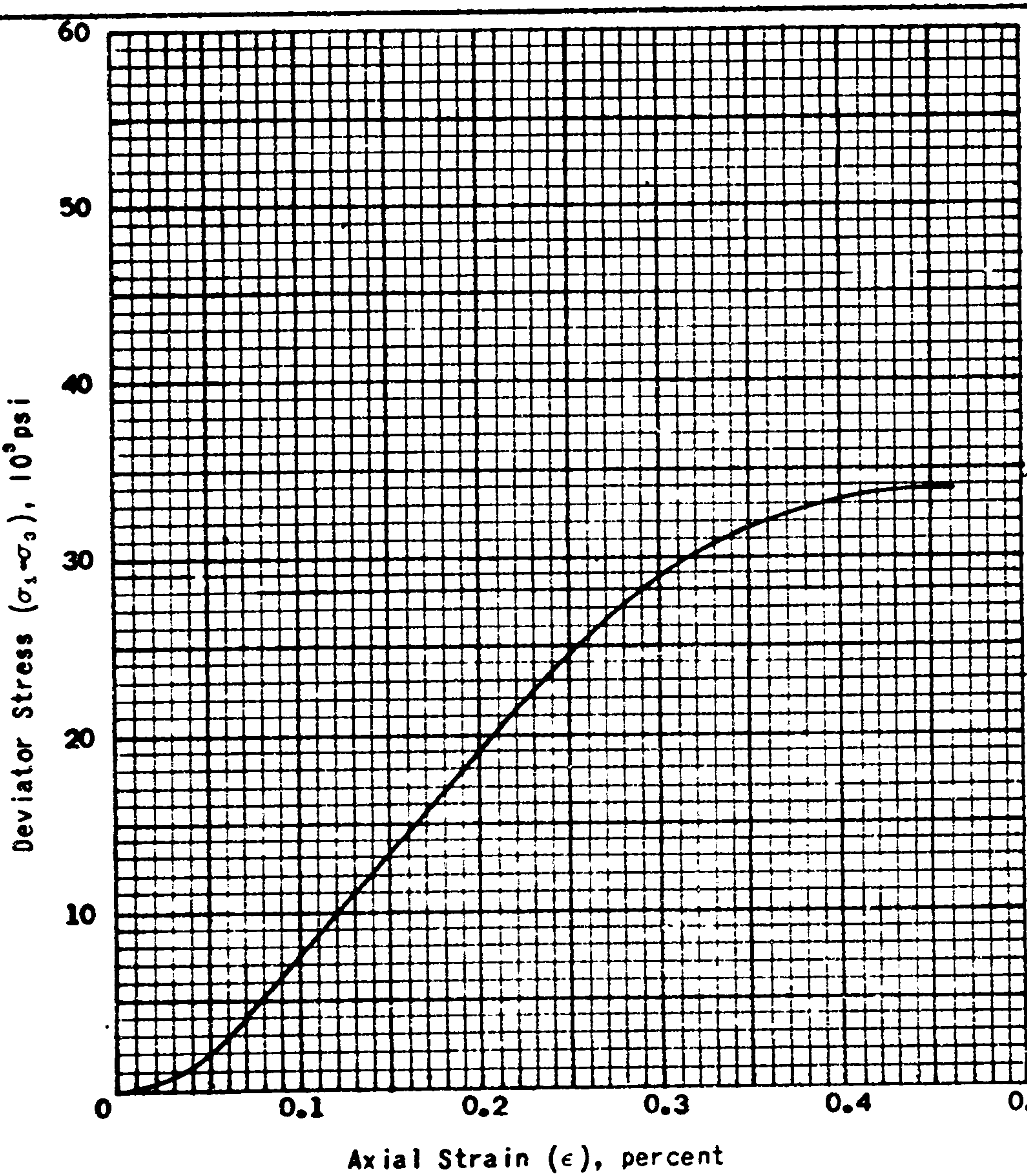


Plane

Failure Plane

MRD FORM 1 APR 64 738

FIGURE 6



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 40, MRD Lab. No. 64/90
Core Depth 574.4-579.4 feet
Core Diam. 2.393 in., Core Ht. 4.80 in.
Core Weight, SSD, 942.2 gm.

Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6psi,
① 450	11.67
②	
③	
④	

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with fine to medium-grained groundmass. Two large (1½ to 2½-in.) crystals of pink feldspar occur in the central section of the core specimen.

In triaxial compression, the core broke predominantly in shear at about 70 degrees from the horizontal. The large feldspar crystals probably affected the breaking characteristics of the core.

MRD FORM
1 APR 64 737

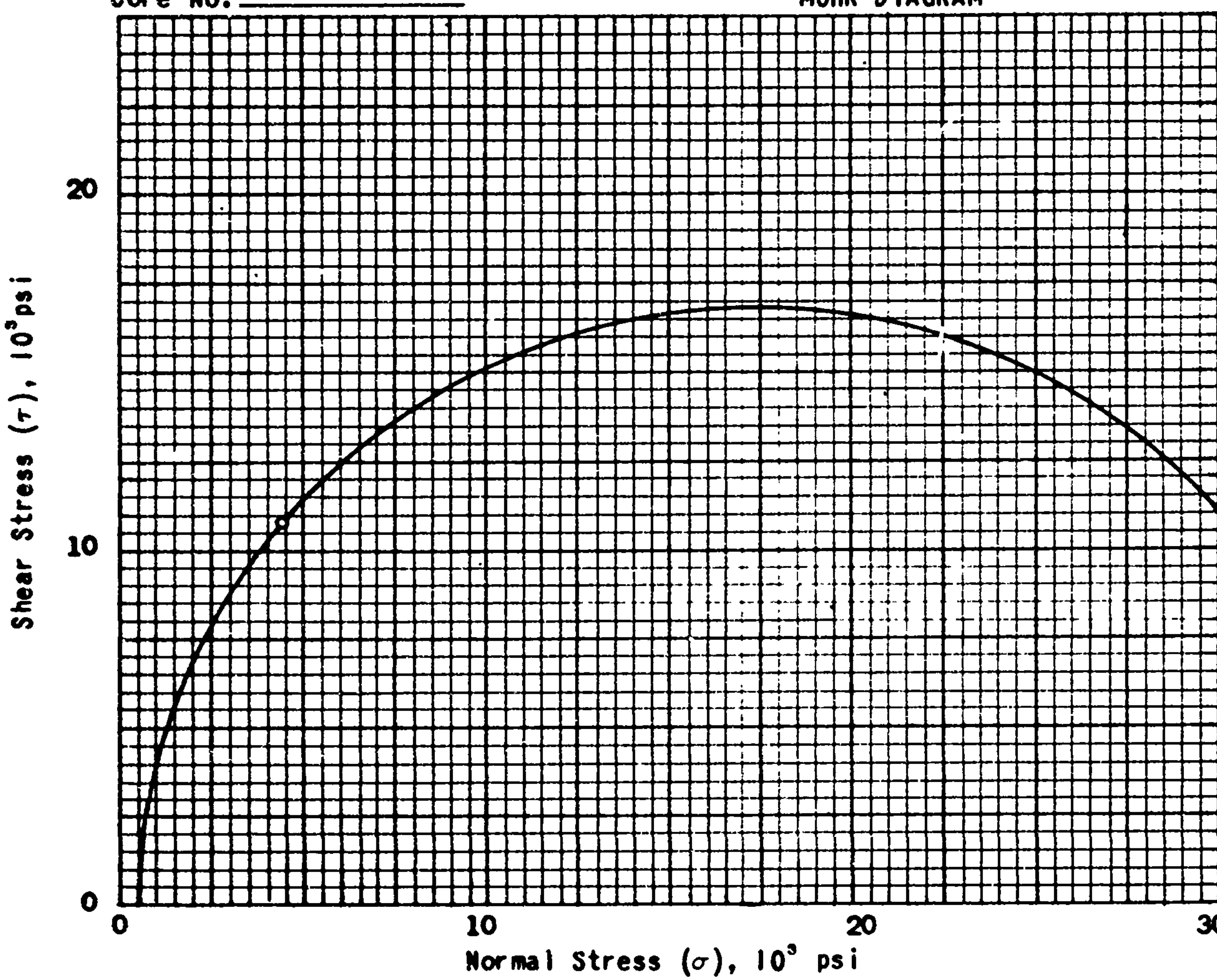
FIGURE 7

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 40

MOHR DIAGRAM

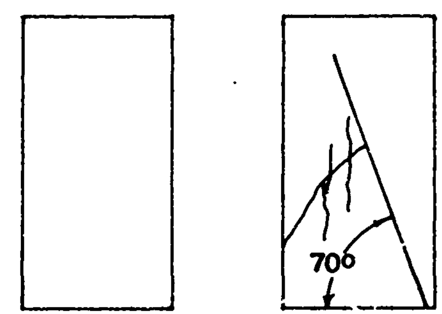


MRD Lab. No. 64/90

PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Plane	Normal Stress (σ), psi Failure Plane ○
450	34,180	-	4,400

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Plane	Shear Stress (τ), psi Failure Plane ○
450	34,180	-	10,830

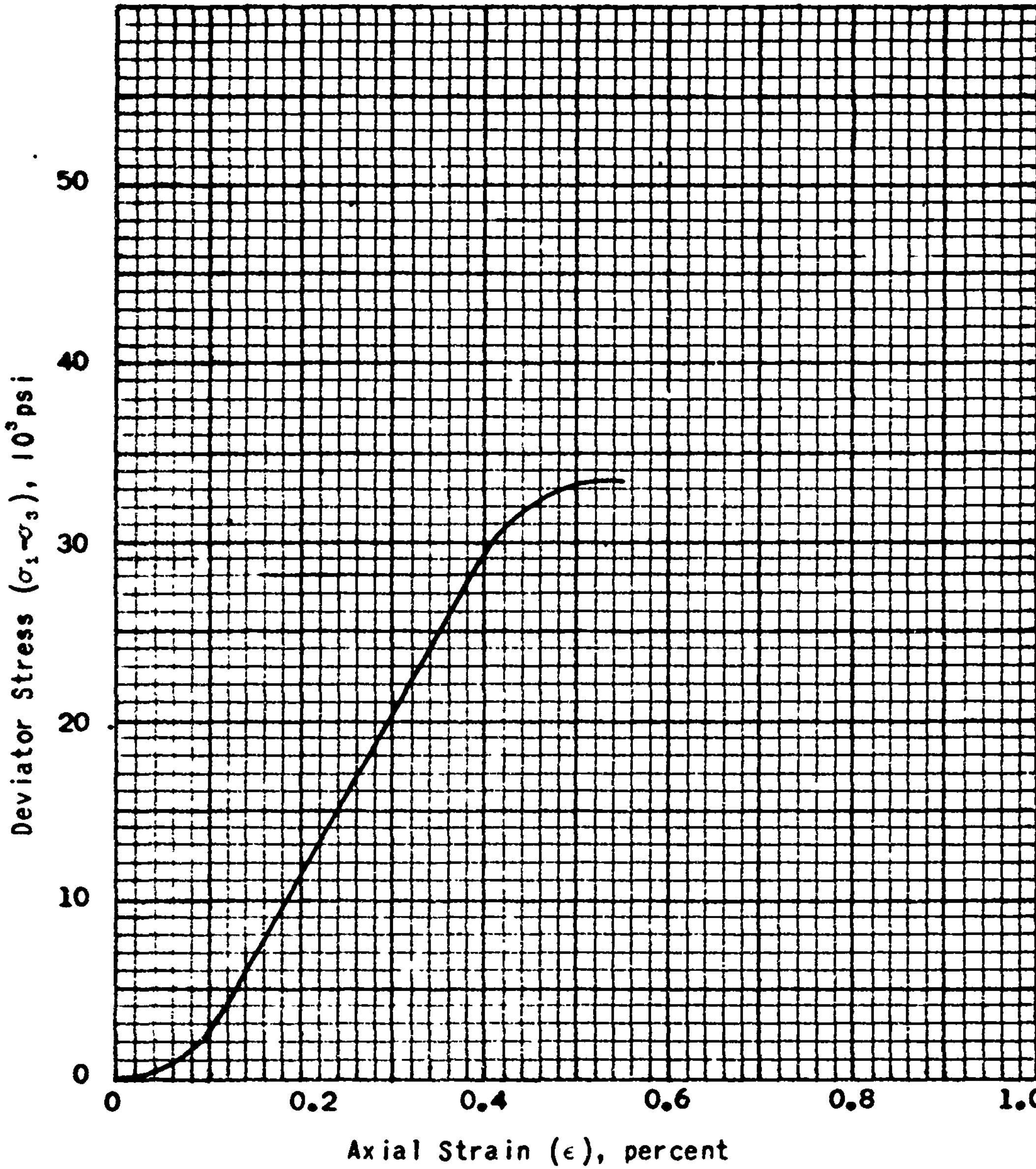


Plane

Failure Plane

MRD FORM 1 APR 64 738

FIGURE 8



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 46, MRD Lab. No. 64/90
Core Depth 495.1-496.5 feet
Core Diam. 2.386 in., Core Ht. 4.76 in.
Core Weight, SSD, 930.6 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6psi,
①	450	9.10
②		
③		
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with fine to medium-grained groundmass. A large feldspar phenocryst occurs in each end section of the core specimen.

In triaxial compression, the core broke with multiple shear fractures at about 65 degrees from the horizontal.

MRD FORM 1 APR 64 737

FIGURE 9

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

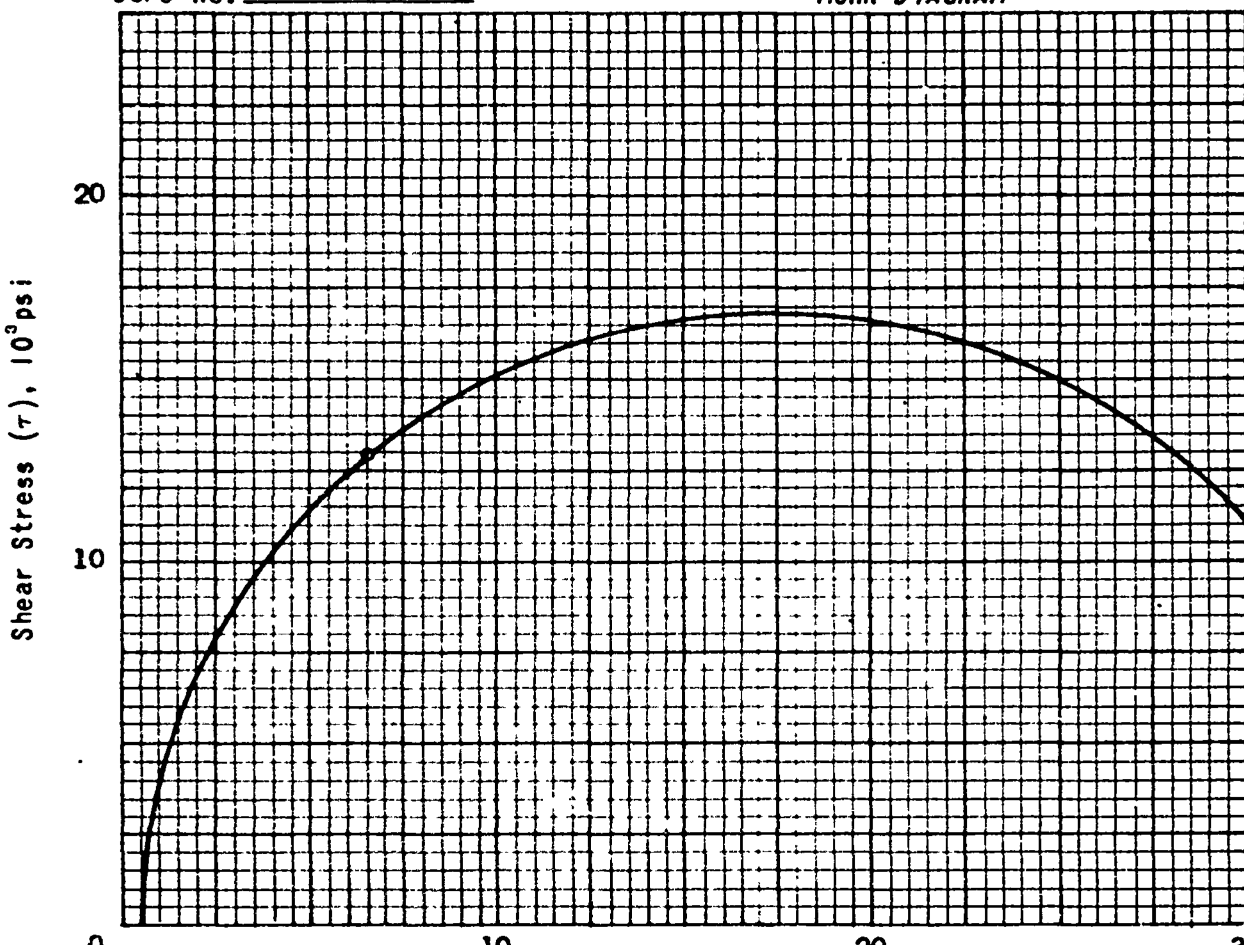
TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 46

MRD Lab. No. 64/90

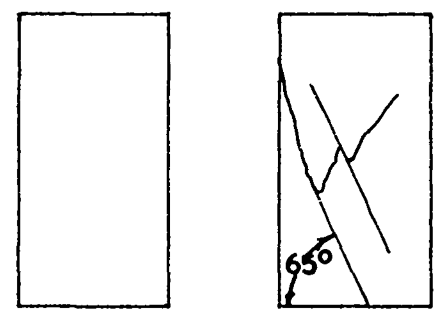
PILEDRIVER

MOHR DIAGRAM



Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Plane	Normal Stress (σ), psi Failure Plane ○
450	34,230	-	6,500

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Plane	Shear Stress (τ), psi Failure Plane ○
450	34,230	-	12,940

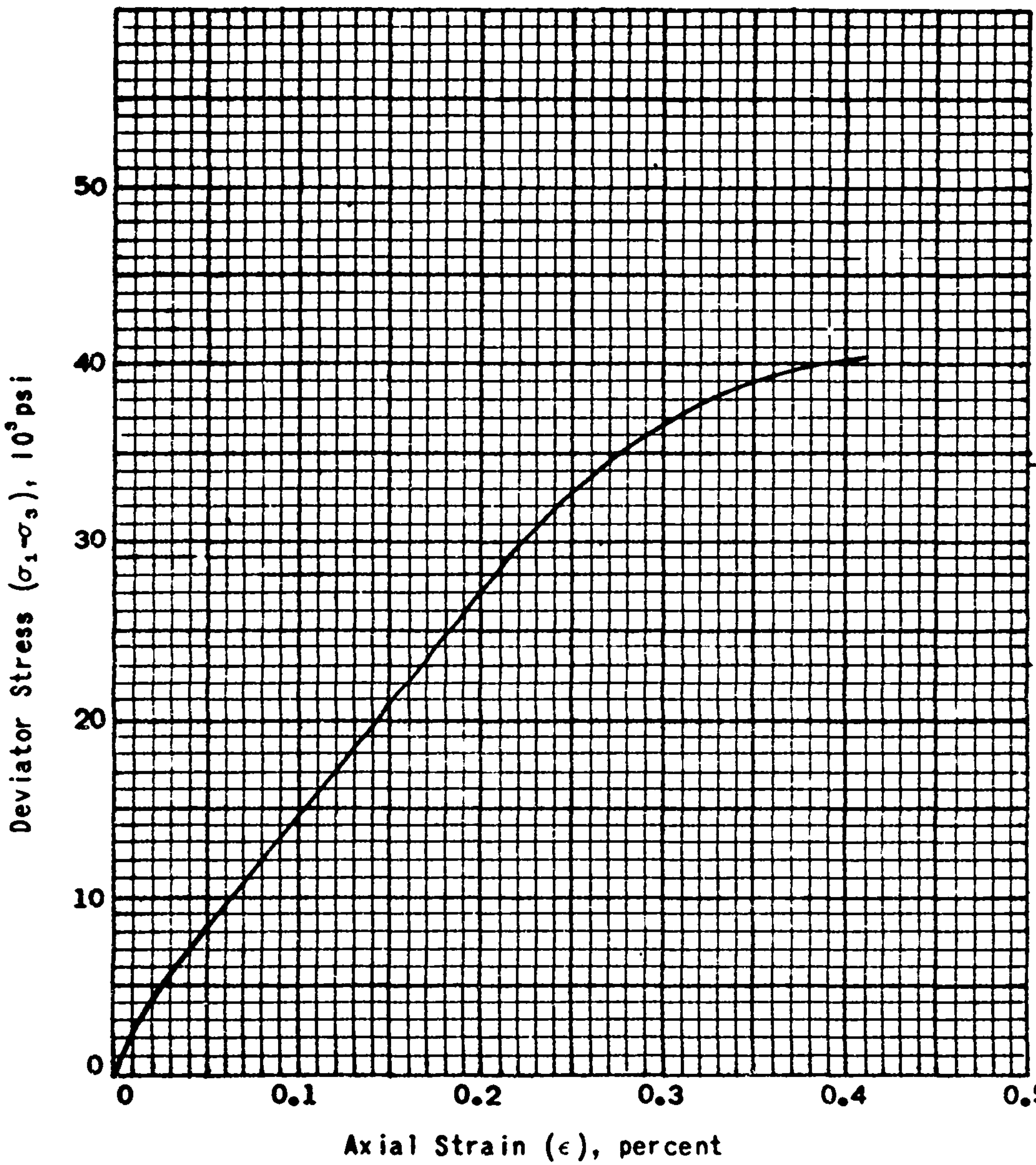


Plane

Failure Plane

MRD FORM 1 APR 64 738

FIGURE 10



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 69, MRD Lab. No. 64/90
Core Depth 775.0-775.9 feet
Core Diam. 2.405 in., Core Ht. 4.77 in.
Core Weight, SSD, 947.4 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi,
①	450	12.50
②		
③		
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:
Quartz Monzonite, light gray, fine to medium-grained, with a few large (½ to 1-in.) crystals of pink feldspar. There is a distinct textural change which occurs irregularly along the long axis of the core in which part of the rock is medium-grained with much scattered flakes of biotite, whereas the other portion is finer grained with less biotite. The large feldspar phenocrysts occur in the fine-grained portion. This probably represents a contact zone of the quartz monzonite with the granodiorite.

In triaxial compression, the core broke partially in shear, but mostly with vertical tension fractures.

MRD FORM
1 APR 64 737

FIGURE 11

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

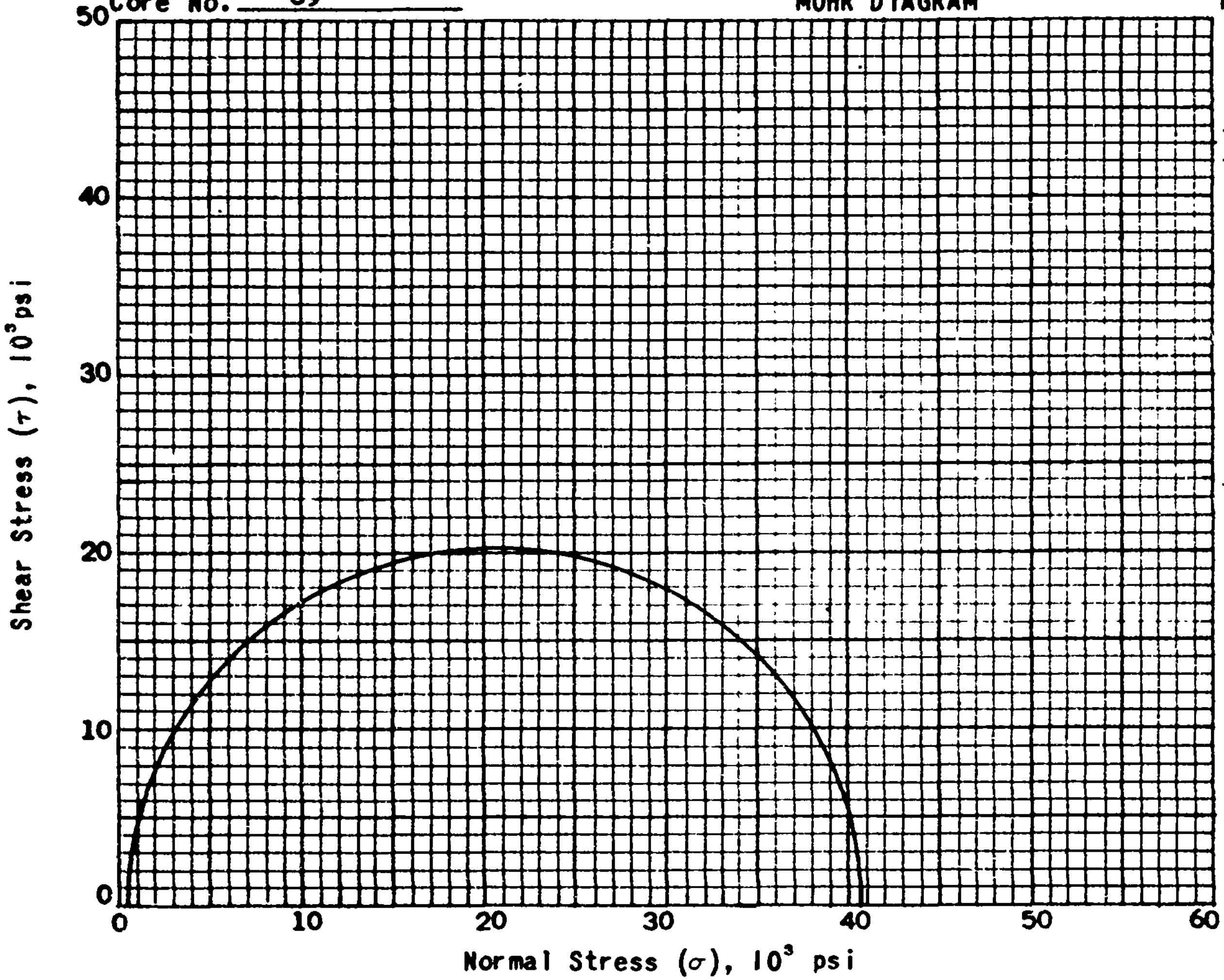
TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 69

MRD Lab. No. 64/90

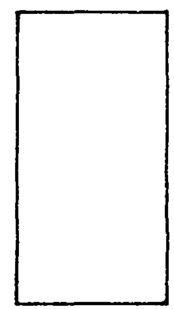
PILEDRIVER

MOHR DIAGRAM

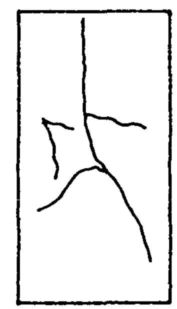


Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Plane	Normal Stress (σ), psi Failure Plane
450	40,060	-	-

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Plane	Shear Stress (τ), psi Failure Plane
450	40,060	-	-



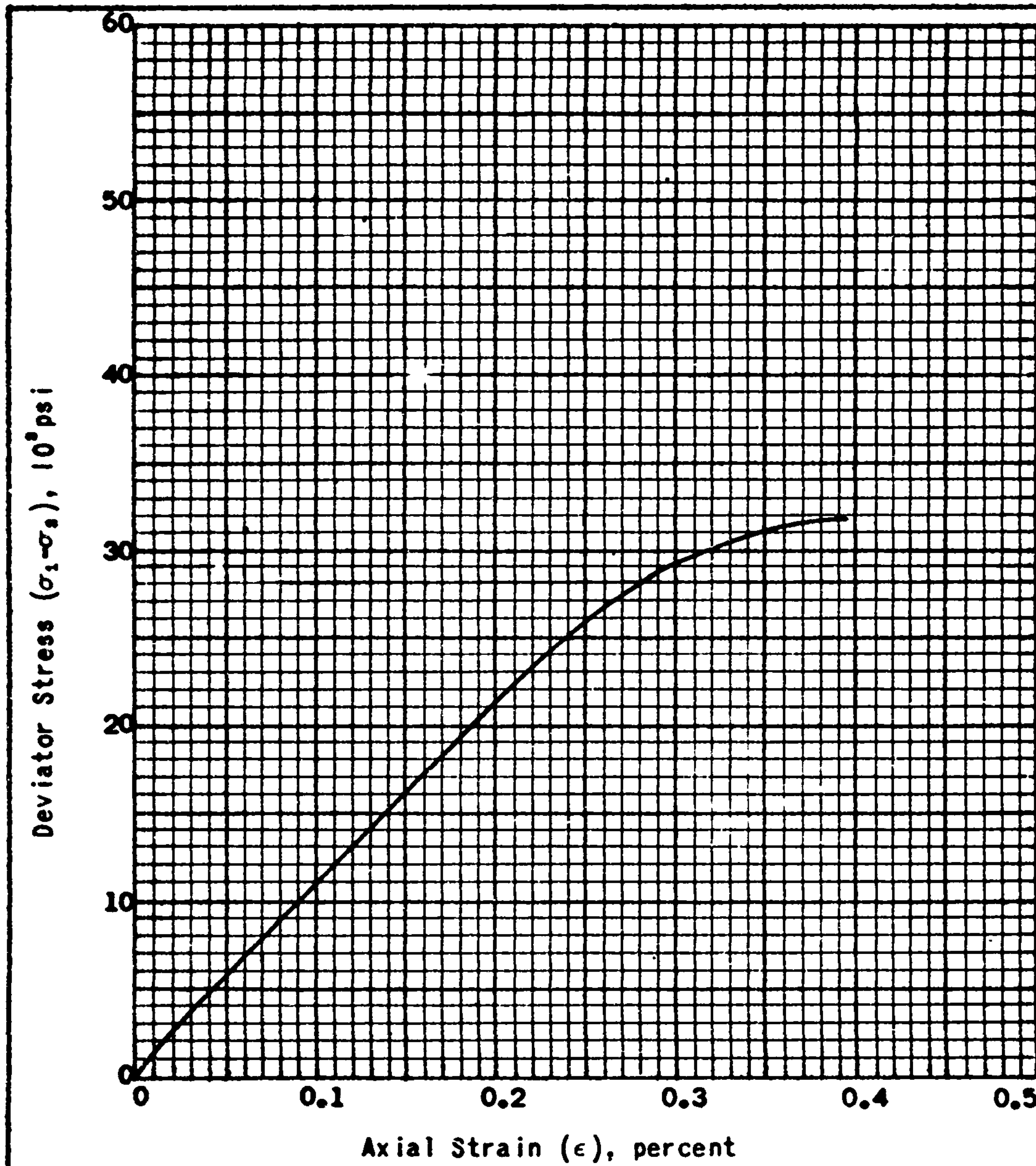
Plane



Failure Plane

MRD FORM 1 APR 64 738

FIGURE 12



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 28 , MRD Lab. No. 64/90
Core Depth 393.1-394.1 feet
Core Diam. 2.386 in., Core Ht. 4.83 in.
Core Weight, SSD , 950.5 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi,
①	1,350	10.00
②		
③		
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with a uniform medium-grained groundmass. One feldspar phenocryst of 7/8-in. length occurred near one end of the core specimen.

In triaxial compression, the core broke with a curved shear plane at about 68 degrees from the horizontal.

MRD FORM
1 APR 64 737

FIGURE 13

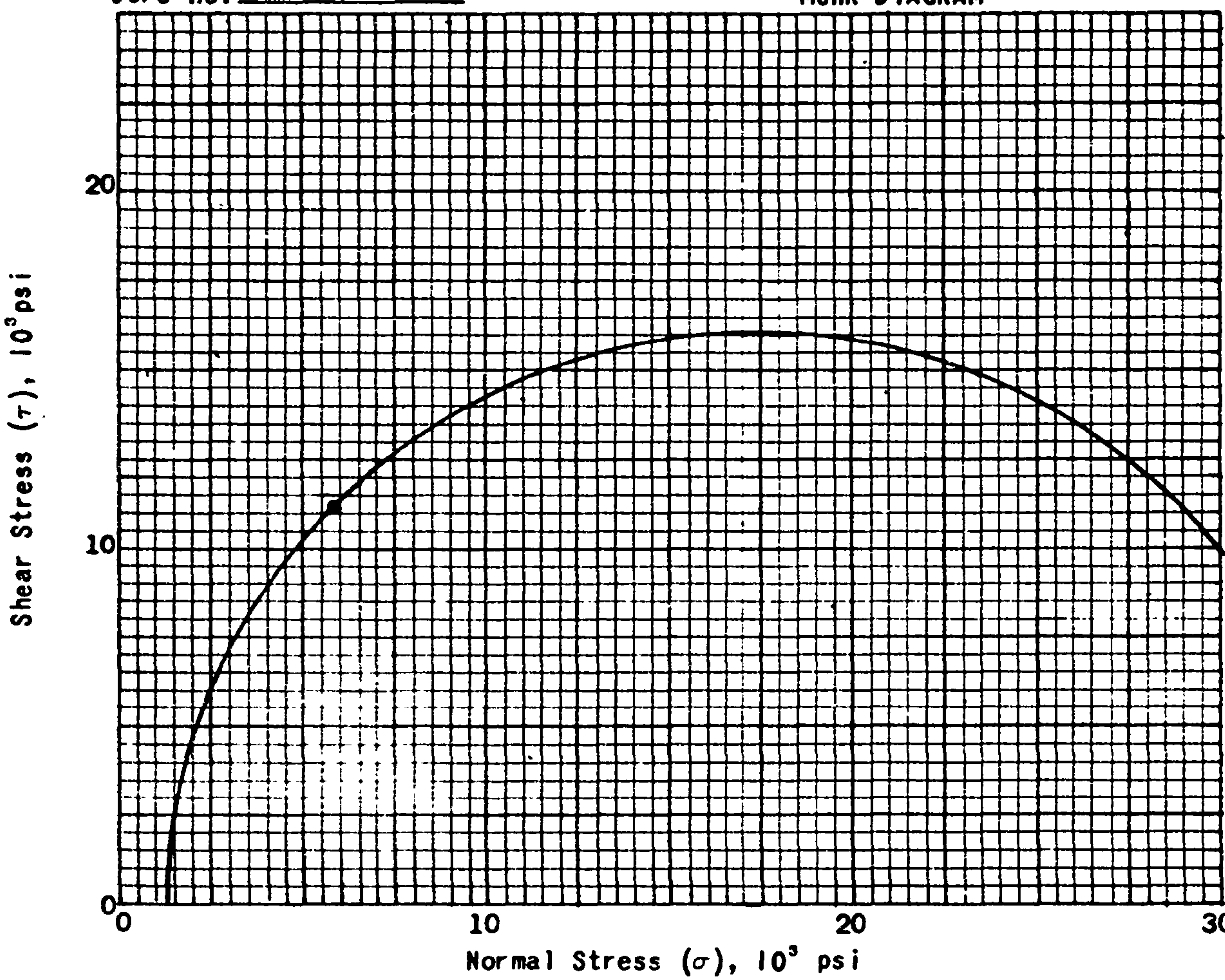
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 28

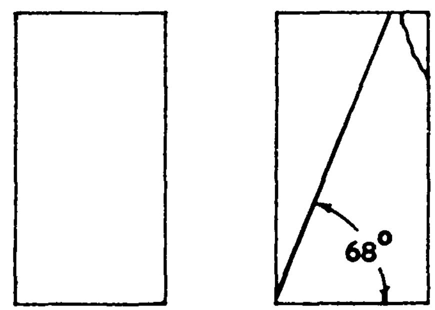
MOHR DIAGRAM

MRD Lab. No. 64/90
PILEDRIVER



Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi: Plane	Normal Stress (σ), psi: Failure Plane
1,350	34,430	-	5,870

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi: Plane	Shear Stress (τ), psi: Failure Plane
1,350	34,430	-	11,160

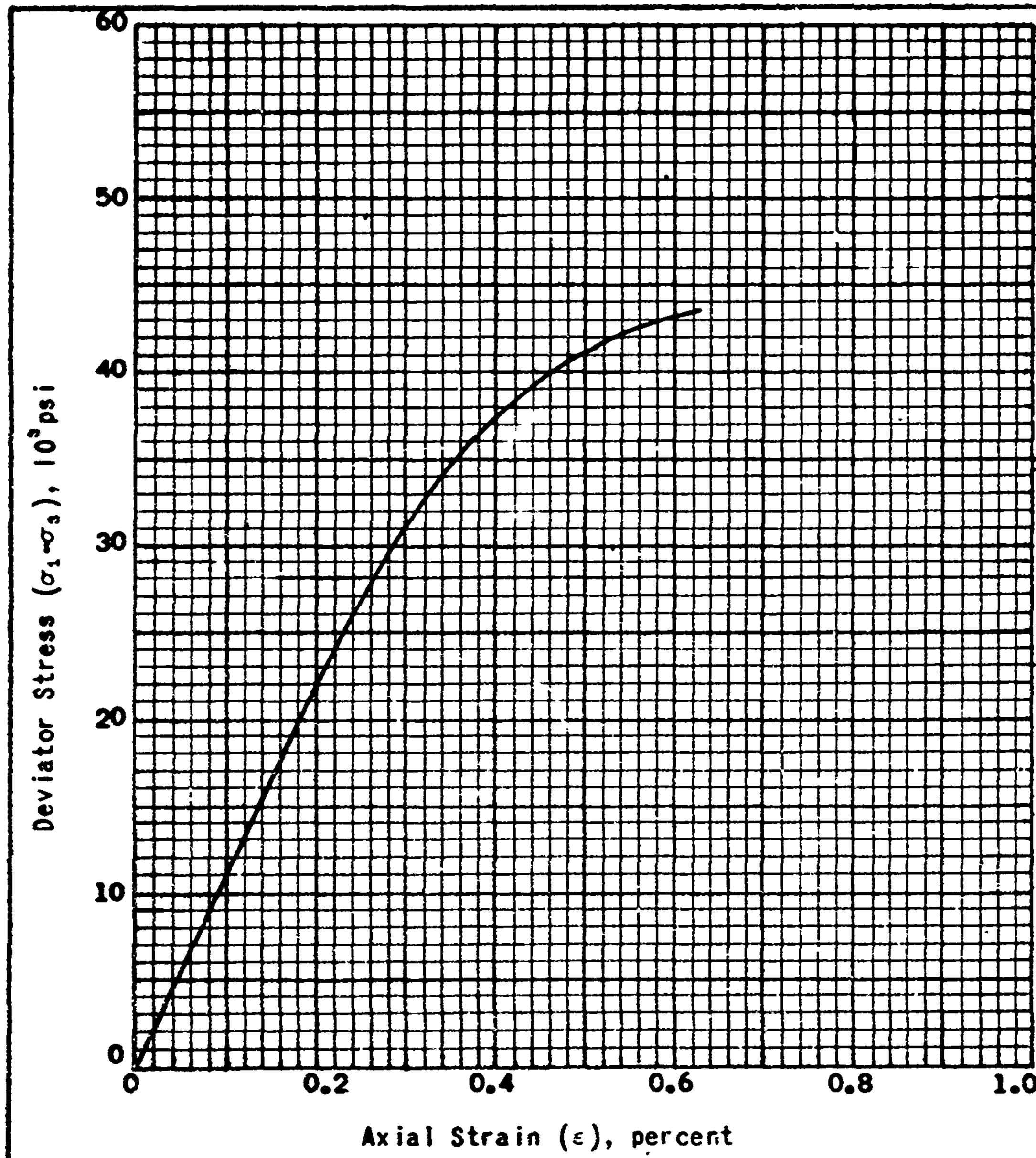


Plane

Failure Plane

MRD FORM
1 APR 64 738

FIGURE 14



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 83, MRD Lab. No. 64/90
Core Depth 589.0-590.4 feet
Core Diam. 2.395 in., Core Ht. 4.85 in.
Core Weight, SSD, 956.5 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi,
①	1,350	11.25
②		
③		
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with fine to medium-grained groundmass. One large feldspar crystal of 1½-in. length occurred in an end section of the core, while another crystal of 1-in. length occurred in the central section.

In triaxial compression, the core broke with multiple shear fractures at about 71 degrees from the horizontal.

MRD FORM
1 APR 64 737

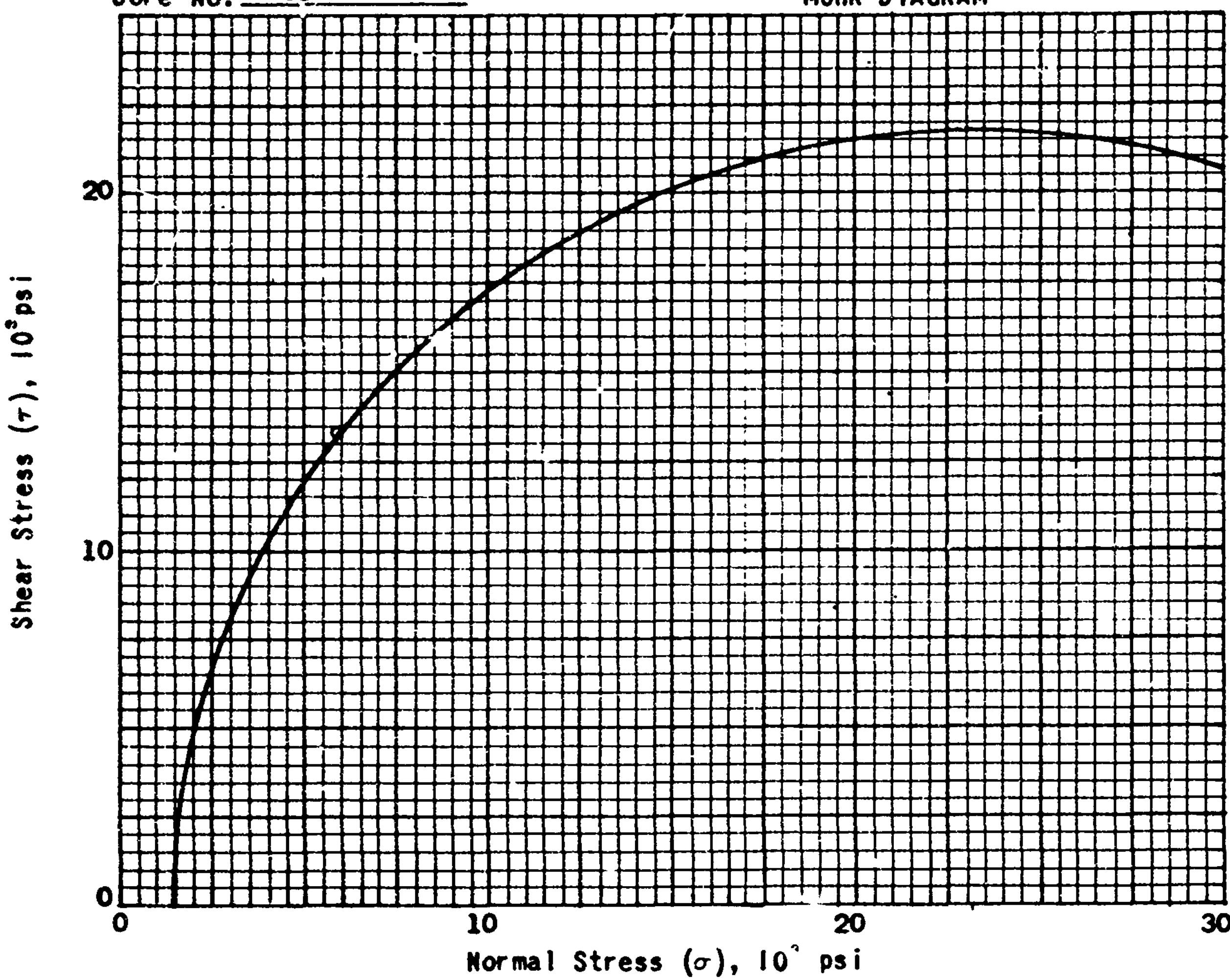
FIGURE 15

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 33

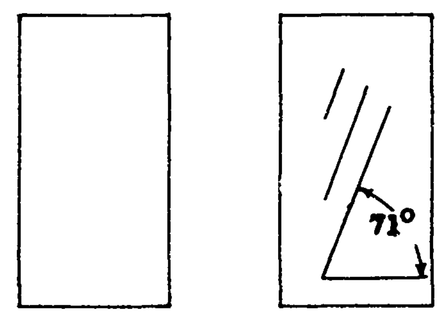
MOHR DIAGRAM



MRD Lab. No. 64/90
PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi: Plane	Normal Stress (σ), psi: Failure Plane ○
1,350	44,900	-	5,970

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi: Plane	Shear Stress (τ), psi: Failure Plane ○
1,350	44,900	-	13,410

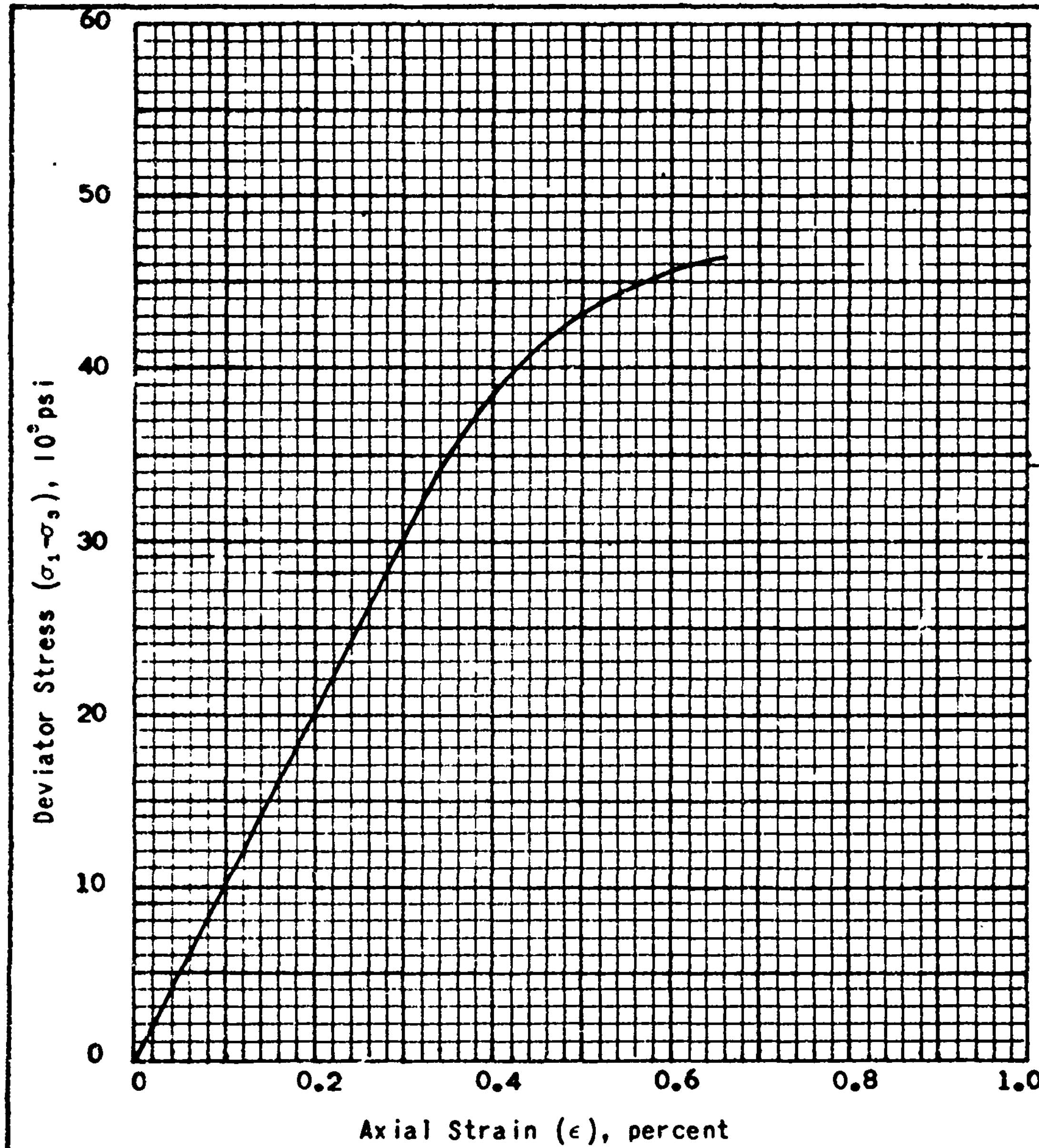


Plane

Failure Plane

MRD FORM
1 APR 64 738

FIGURE 16



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 136, MRD Lab. No. 64/90
Core Depth 778.6-779.2 feet
Core Diam. 2.407 in., Core Ht. 4.74 in.
Core Weight, SSD, 940.0 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6psi,
①	1,350	10.31
②		
③		
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium to fine-grained groundmass. No large crystals of feldspar were present in the specimen.

In triaxial compression, the core broke predominantly in shear at about 72 degrees from the horizontal.

MRD FORM 1 APR 64 737

FIGURE 17

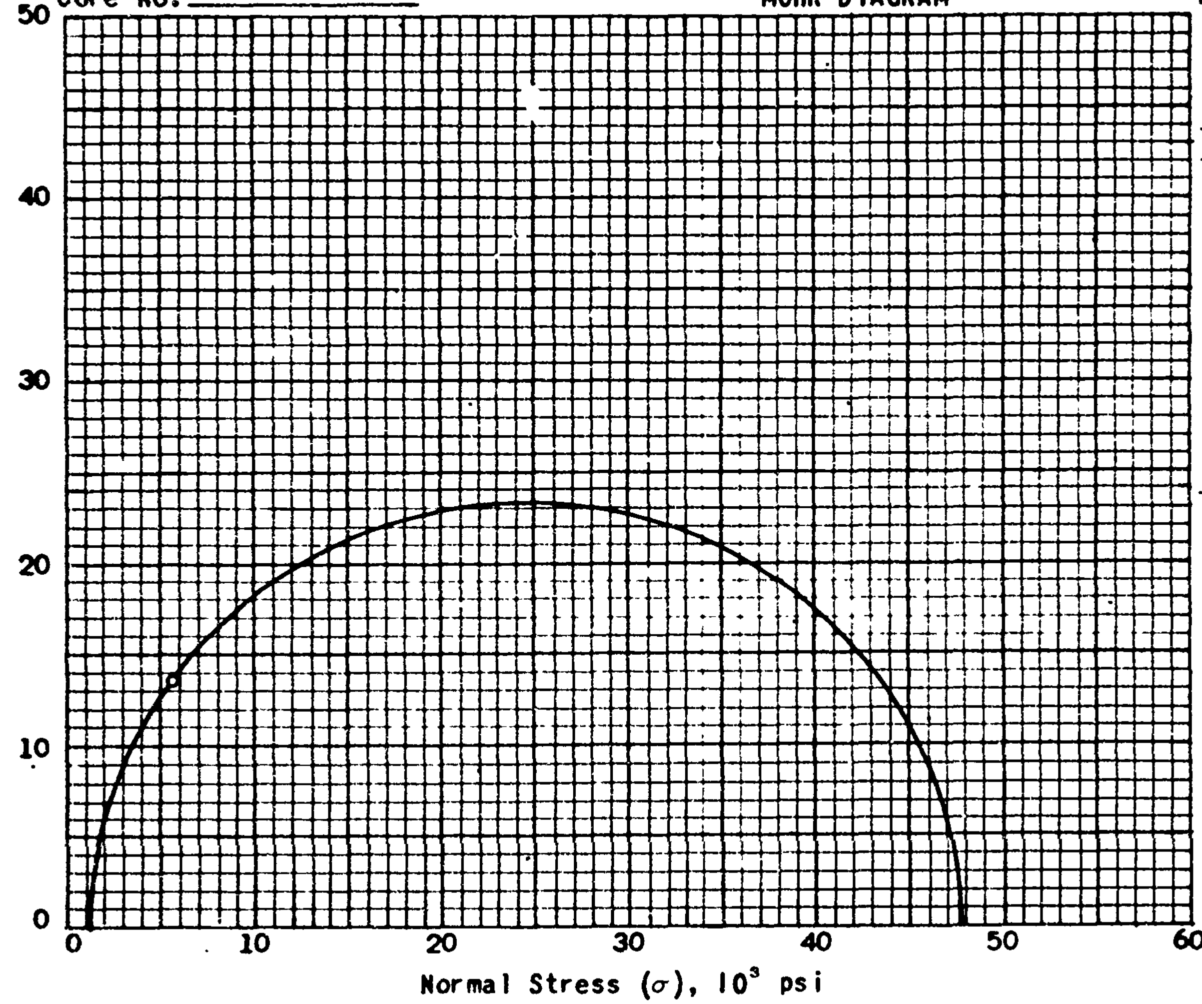
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 136

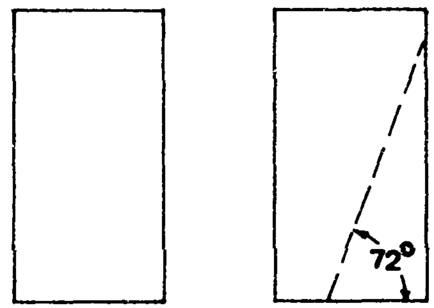
MRD Lab. No. 64/90
PILEDRIVER

MOHR DIAGRAM



Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi: Plane	Normal Stress (σ), psi: Failure Plane ○
1,350	47,590	-	5.74

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi: Plane	Shear Stress (τ), psi: Failure Plane
1,350	47,590	-	13.59

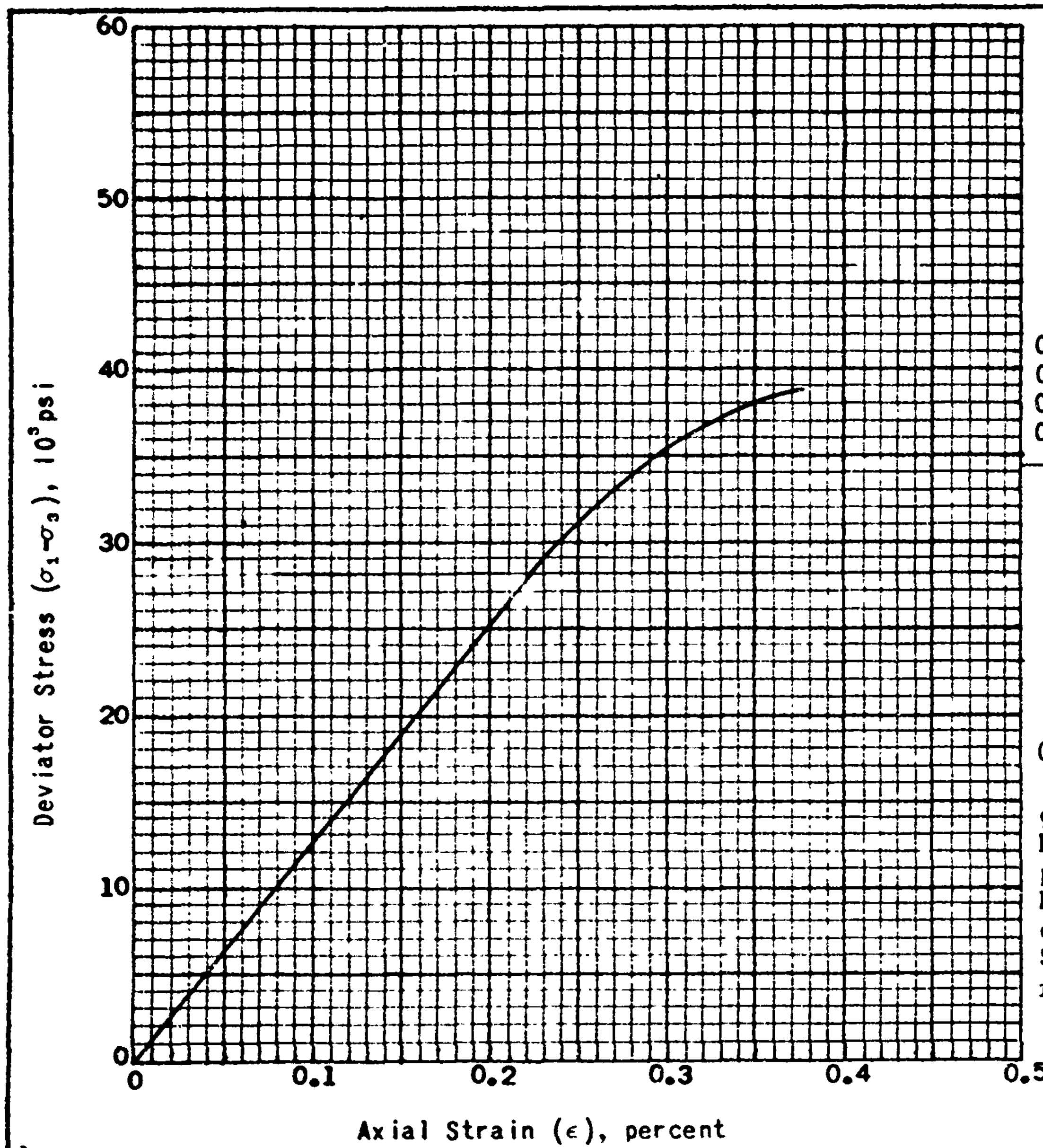


Plane

Failure Plane

MRD FORM
1 APR 64 738

FIGURE 18



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 130, MRD Lab. No. 64/90
Core Depth 642.9-644.1 feet
Core Diam. 2.387 in., Core Ht. 4.84 in.
Core Weight, SSD, 943.8 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6psi,
①	150	12.63
②		
③		
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, uniform, fine-grained portion in contact at 41 degrees from the horizontal with medium gray, slightly porphyritic portion having a fine-grained groundmass. A healed fracture dipping 72 degrees occurs in the darker colored portion of the core specimen. Small masses of pyrite are common throughout the rock.

In triaxial compression, the core broke with tension fractures across the healed contact zone.

MRD FORM
1 APR 64 737

FIGURE 19

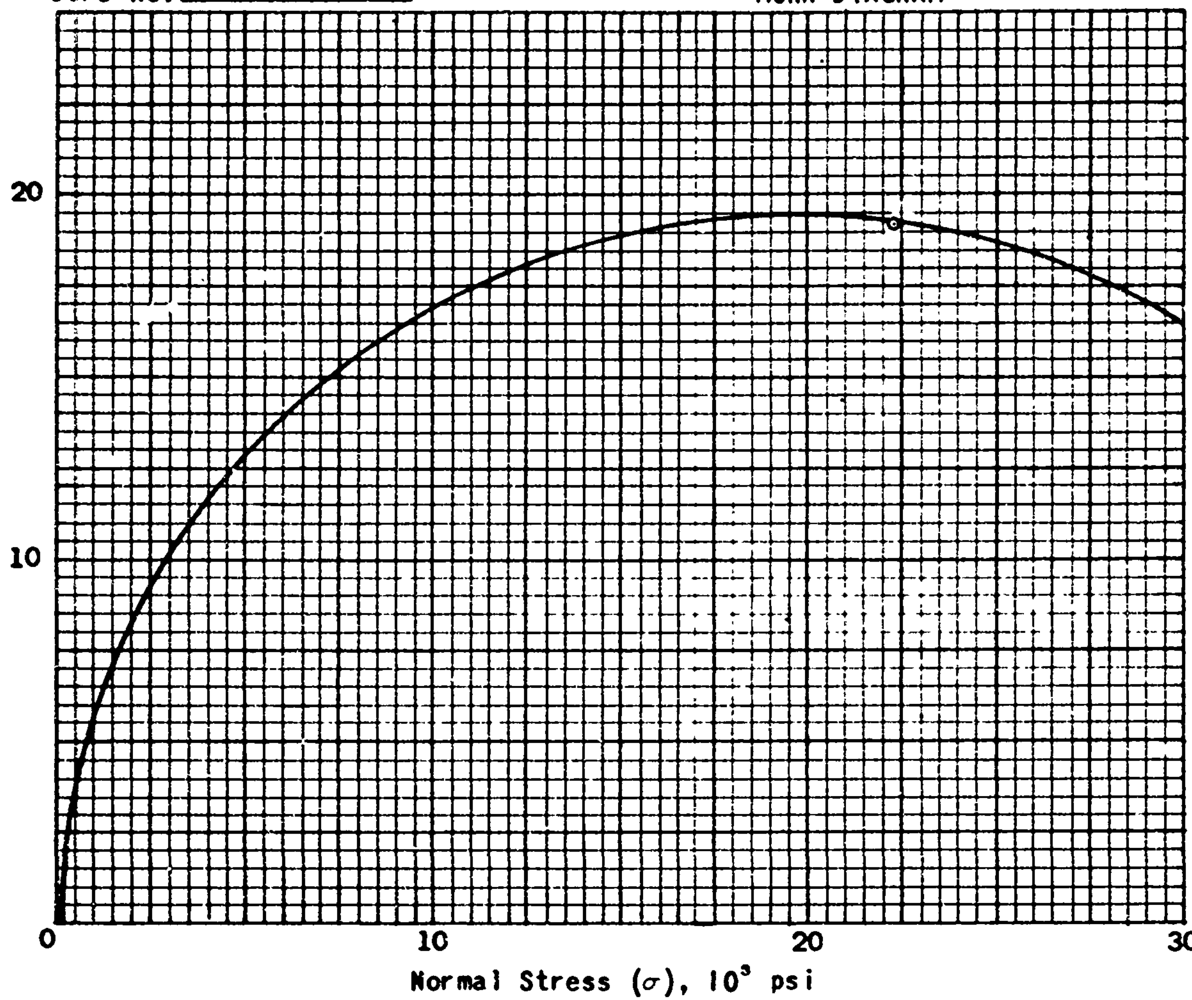
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 130

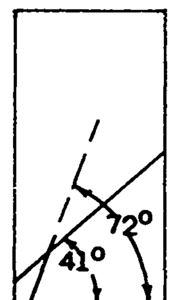
MOHR DIAGRAM

MRD Lab. No. 64/90
PILEDRIVER

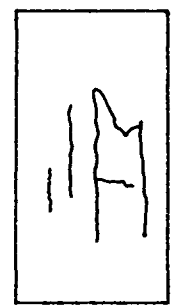


Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi: Healed Contact Plane o	Normal Stress (σ), psi: Failure Plane
150	39,050	22,320	-

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi: Healed Contact Plane o	Shear Stress (τ), psi: Failure Plane
150	39,050	19,260	-

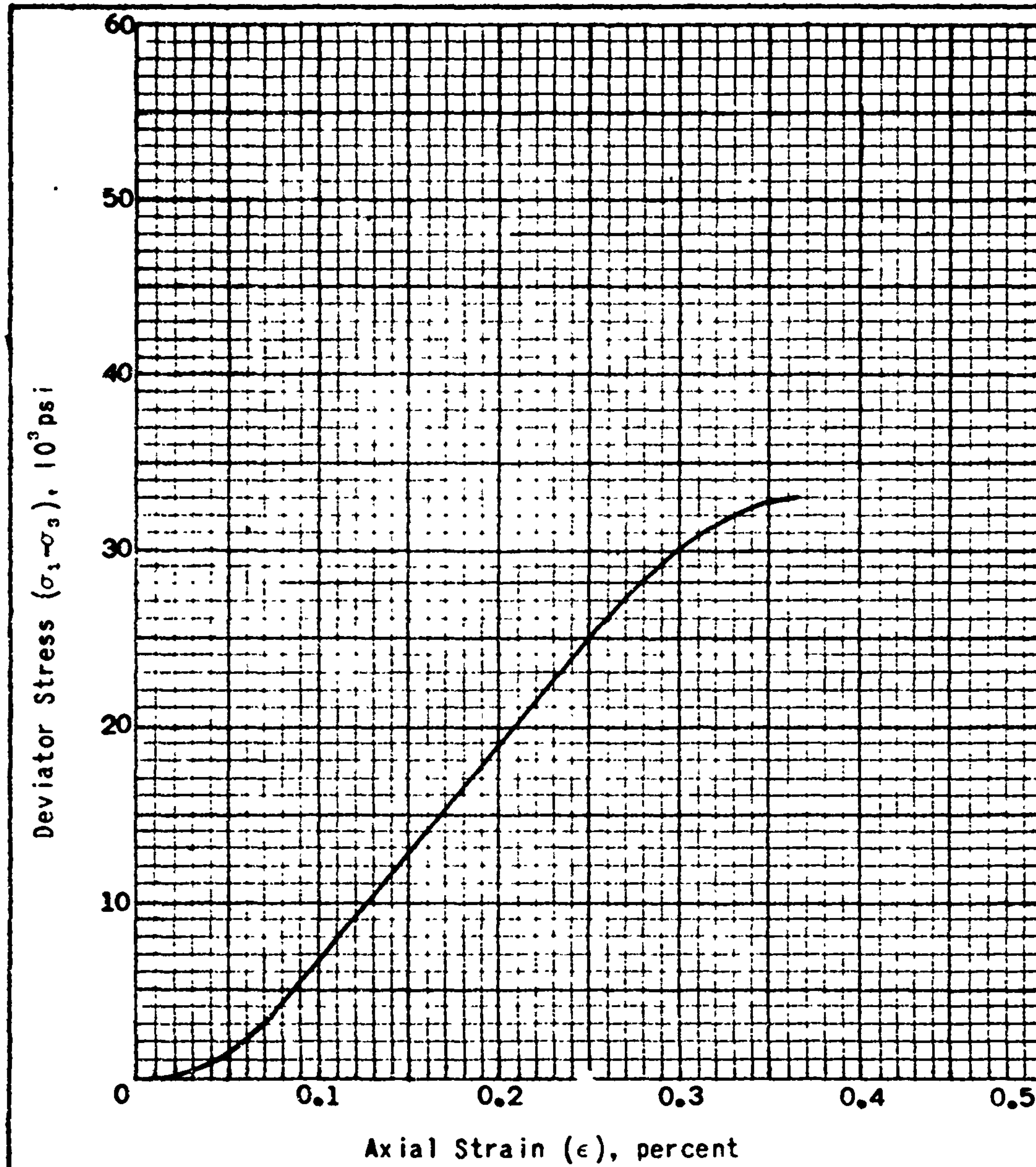


Healed Contact Plane


Failure Plane

MRD FORM
1 APR 64 738

FIGURE 20



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 105, MRD Lab. No. 64/90
Core Depth 467.3-468.1 Feet
Core Diam. 2.400 in., Core Ht. 4.85 in.
Core Weight, OD, 957.8 gm.

	Confining Pressure (σ_3), psi	Modulus of Elasticity, 10^6 psi
1	150	12.35
2		
3		
4		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. One large feldspar phenocryst of 1-in. length occurs near one end of the core specimen. A 1/4-in. thick healed joint dips about 55 degrees. Slight alteration associated with pyrite masses occurs at one end of the core.

In triaxial compression, the core broke essentially with vertical tension fractures across the healed joint plane.

MRD FORM 1 APR 64 737

FIGURE 21

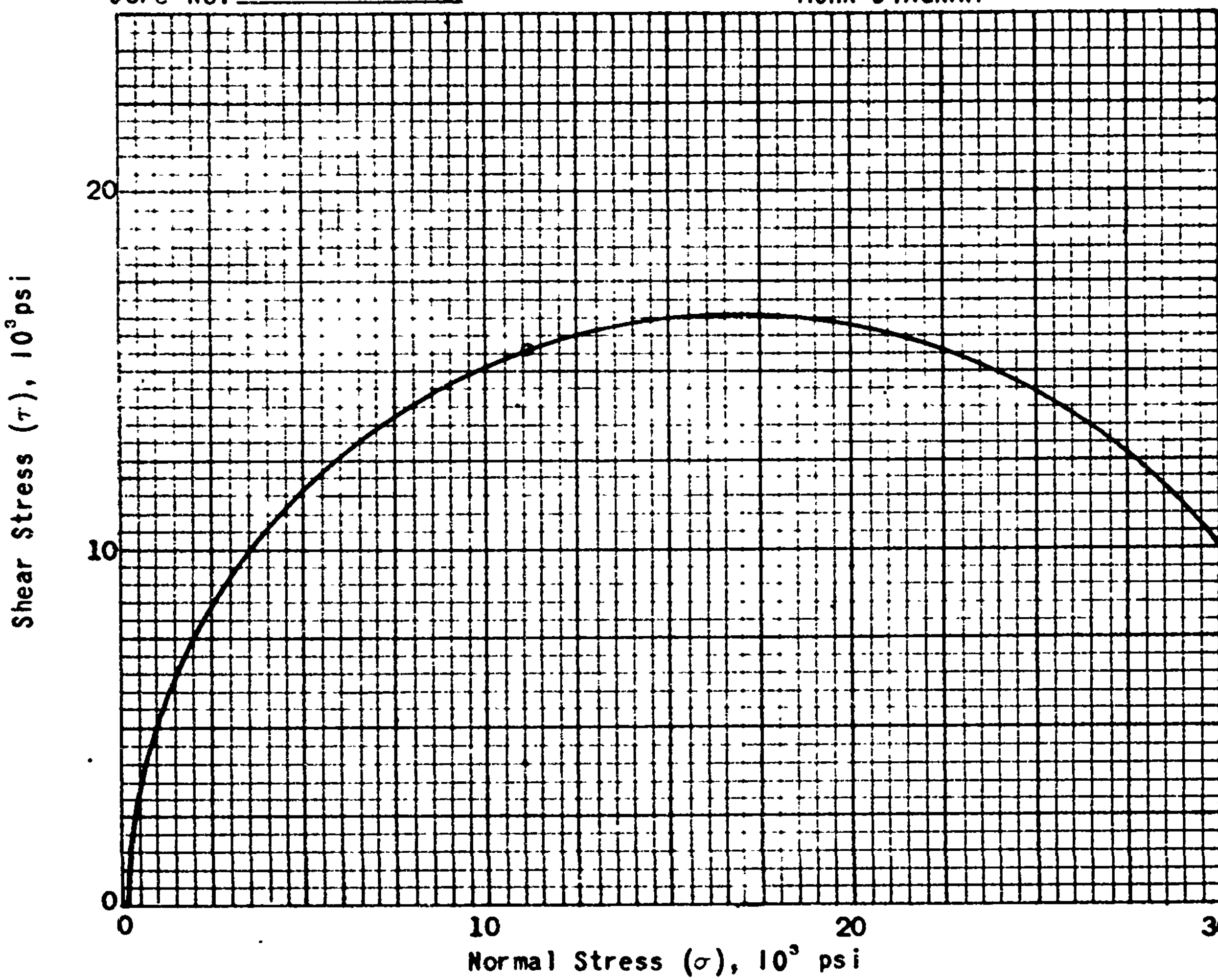
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 105

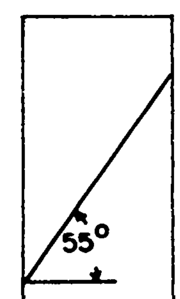
MOHR DIAGRAM

MRD Lab. No. 64/90 PILEDRIVER

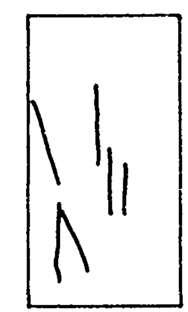


Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Healed Joint Plane	Normal Stress (σ), psi Failure Plane
150	33,200	11,020	-

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Healed Joint Plane	Shear Stress (τ), psi Failure Plane
150	33,200	15,530	-



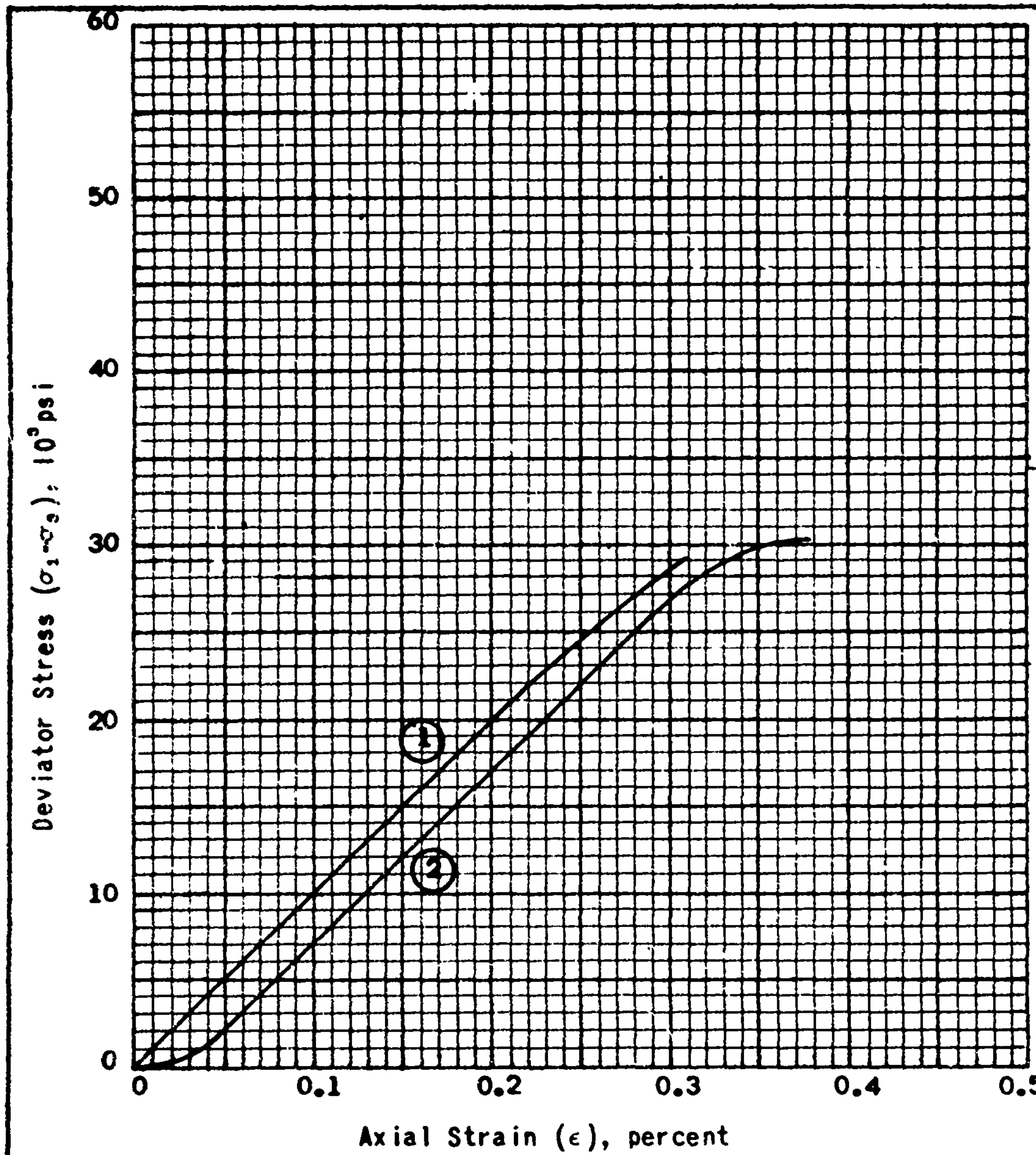
Healed Joint Plane



Failure Plane

MRD FORM 1 APR 64 738

FIGURE 22



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 142, MRD Lab. No. 64/90
Core Depth 325.2-326.2 feet
Core Diam. 2.403 in., Core Ht. 4.87 in.
Core Weight, SSD, 968.7 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6psi,
1	150	10.00
2	450	10.00
3		
4		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. A few feldspar phenocrysts of 1-in. length occur in the center and toward one end of the core specimen. A well-healed fracture filled mainly with pyrite dips about 60 degrees. The rock is somewhat altered along the fracture plane. Another small joint lined with calcite occurs at 74 degrees from the horizontal, cutting across the first joint.

In triaxial compression, the core broke essentially along the healed joint plane. Some vertical tension fractures occurred with the second stage confining pressure.

MRD FORM 737
1 APR 64

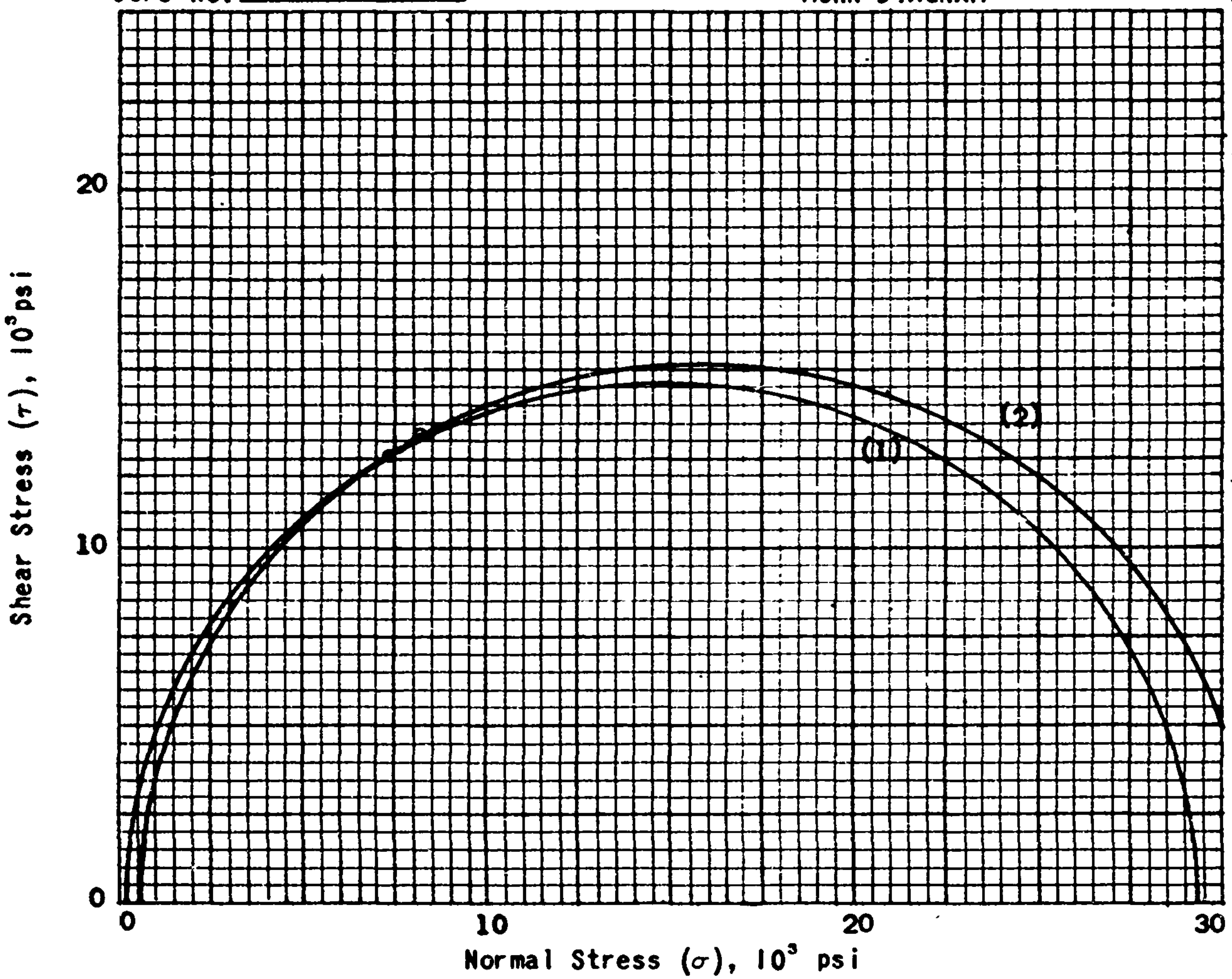
FIGURE 23

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 142

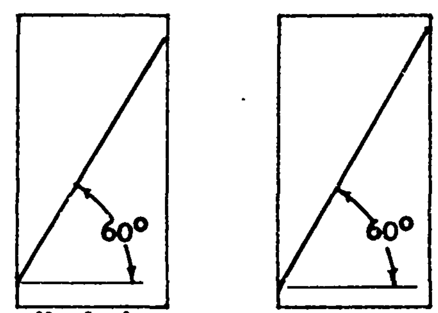
MOHR DIAGRAM



MRD Lab. No. 64/90
PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Healed Joint Plane ○	Normal Stress (σ), psi Failure Plane ○
(1) 150	29,310	7,440	7,440
(2) 450	30,800	8,040	8,040

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Healed Joint Plane ○	Shear Stress (τ), psi Failure Plane ○
(1) 150	29,310	12,630	12,630
(2) 450	30,800	13,140	13,140

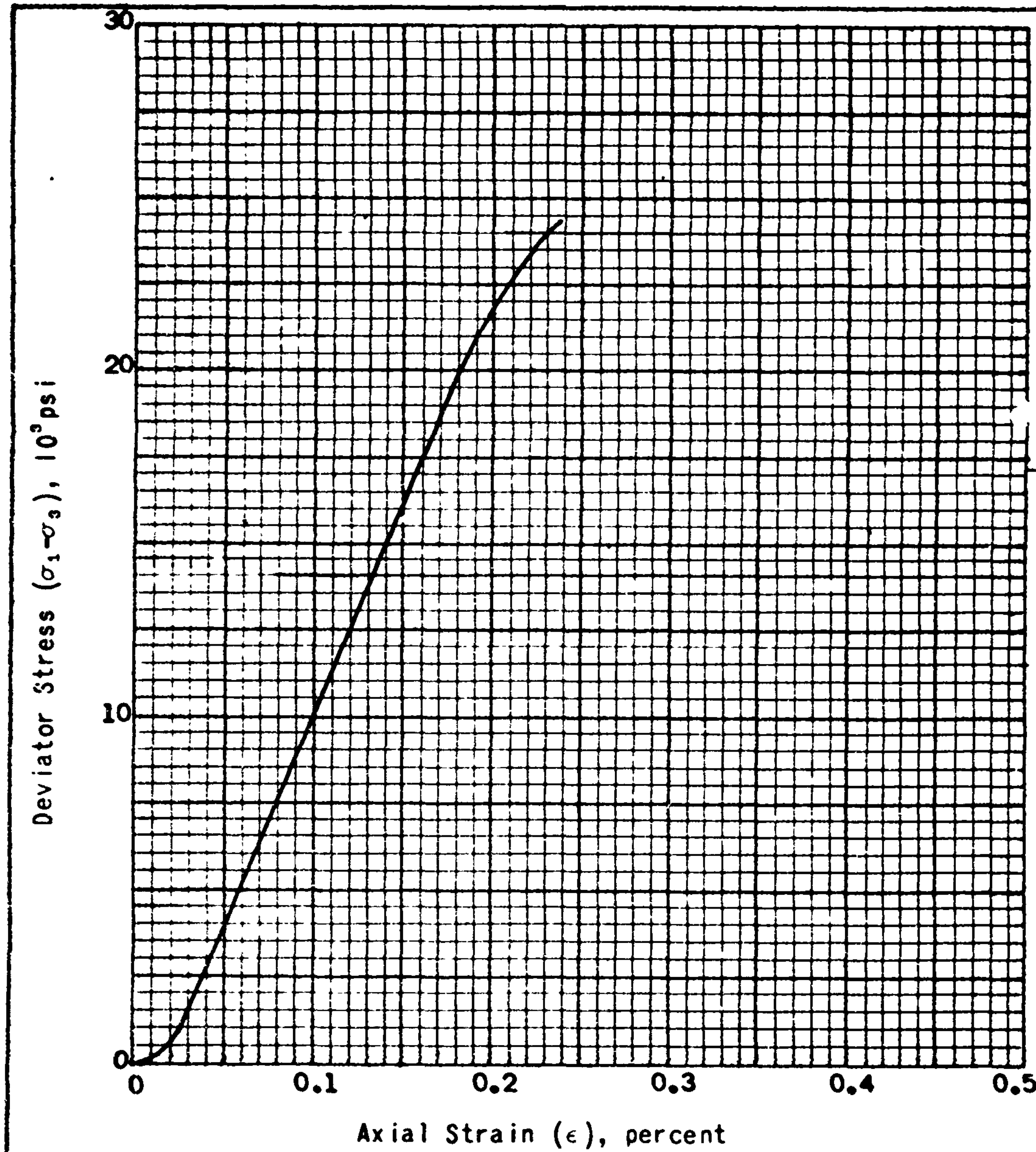


Healed Joint Plane

Failure Plane

MRD FORM
1 APR 64 738

FIGURE 24



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 143 , MRD Lab. No. 64/90
Core Depth 325.2-326.2 feet
Core Diam. 2.402 in., Core Ht. 4.83 in.
Core Weight, SSD , 956.5 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6psi,
①	150	12.50
②		
③		
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. No larger crystals of feldspar than ½-in. length were present in the specimen. Two well-healed joints, one dipping 62 degrees, the other dipping in the opposite direction at 69 degrees occur in the core. These joints are filled with pyrite, calcite, and feldspar.

In triaxial compression, the core broke essentially with vertical tension fractures across the healed joint planes.

MRD FORM
1 APR 64 737

FIGURE 25

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

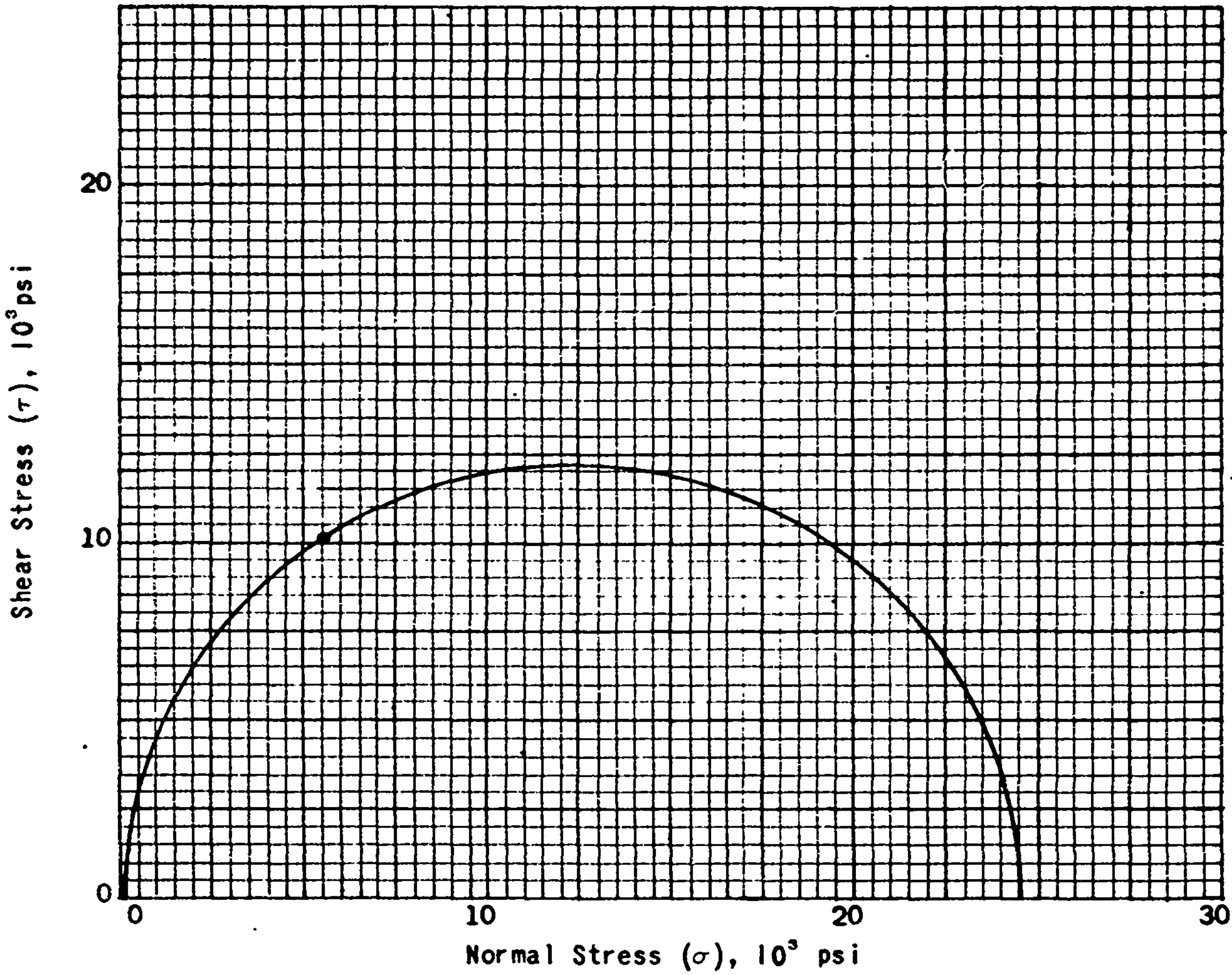
TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 143

MOHR DIAGRAM

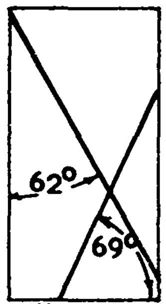
MRD Lab. No. 64/90

PILEDRIVER

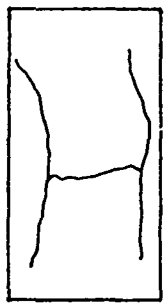


Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Healed Joint Plane	Normal Stress (σ), psi Failure Plane
150	24,520	5,510	-

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Healed Joint Plane	Shear Stress (τ), psi Failure Plane
150	24,520	10,090	-



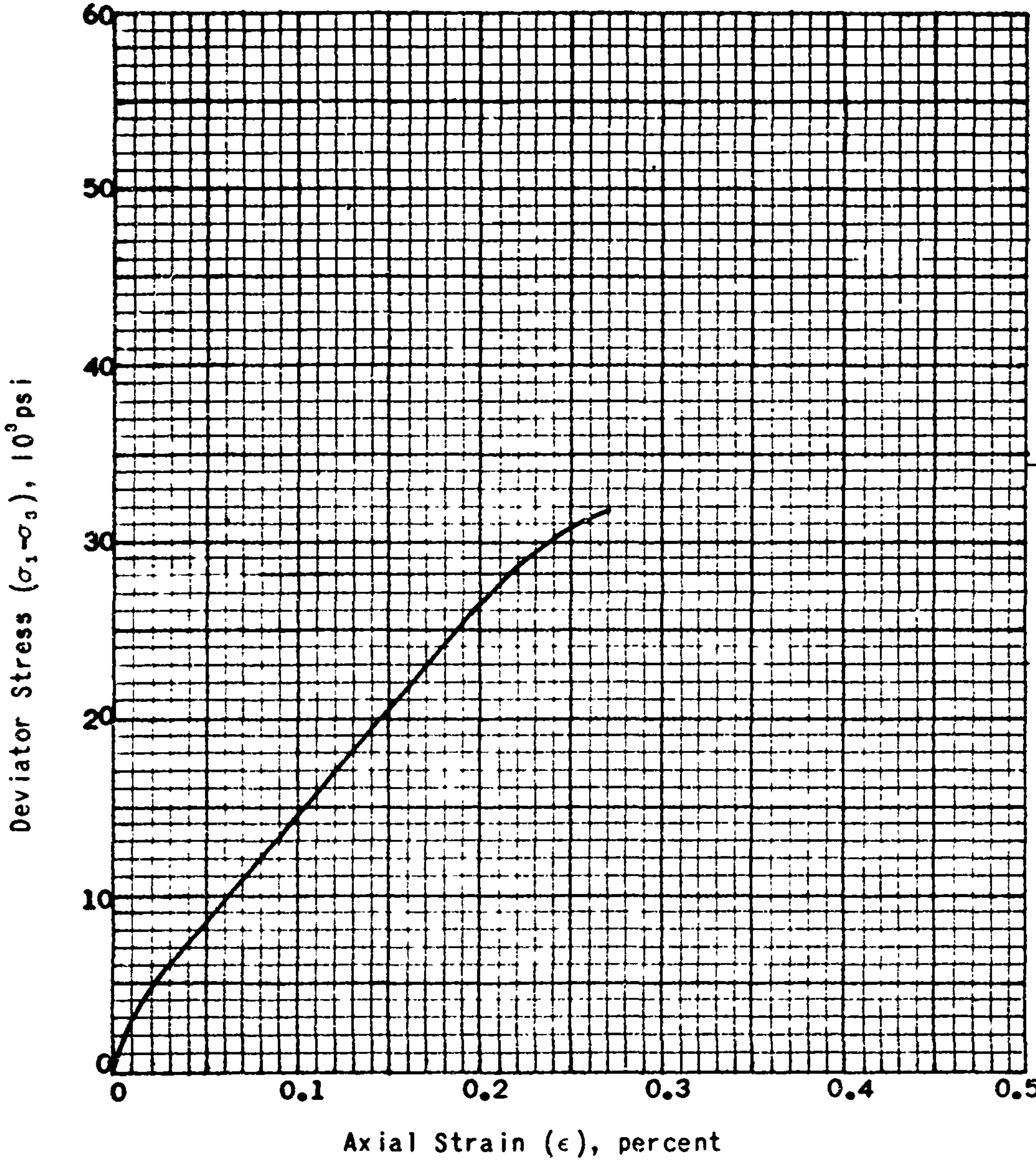
Healed Joint Plane



Failure Plane

MRD FORM 1 APR 64 738

FIGURE 26



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 131 , MRD Lab. No. 64/90
Core Depth 713.0-714.2 feet
Core Diam. 2.404 in., Core Ht. 4.84 in.
Core Weight, SSD , 970.3 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi.
①	450	11.90
②		
③		
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. The rock has a spotted appearance due to scattered flakes of biotite. One large feldspar crystal of 3/4-in. length occurs near one end of the core specimen. Two parallel well-healed joints dipping at about 44 degrees are present.

In triaxial compression, the core broke essentially with vertical tension fractures across the healed joint planes.

MRD FORM
1 APR 64 737

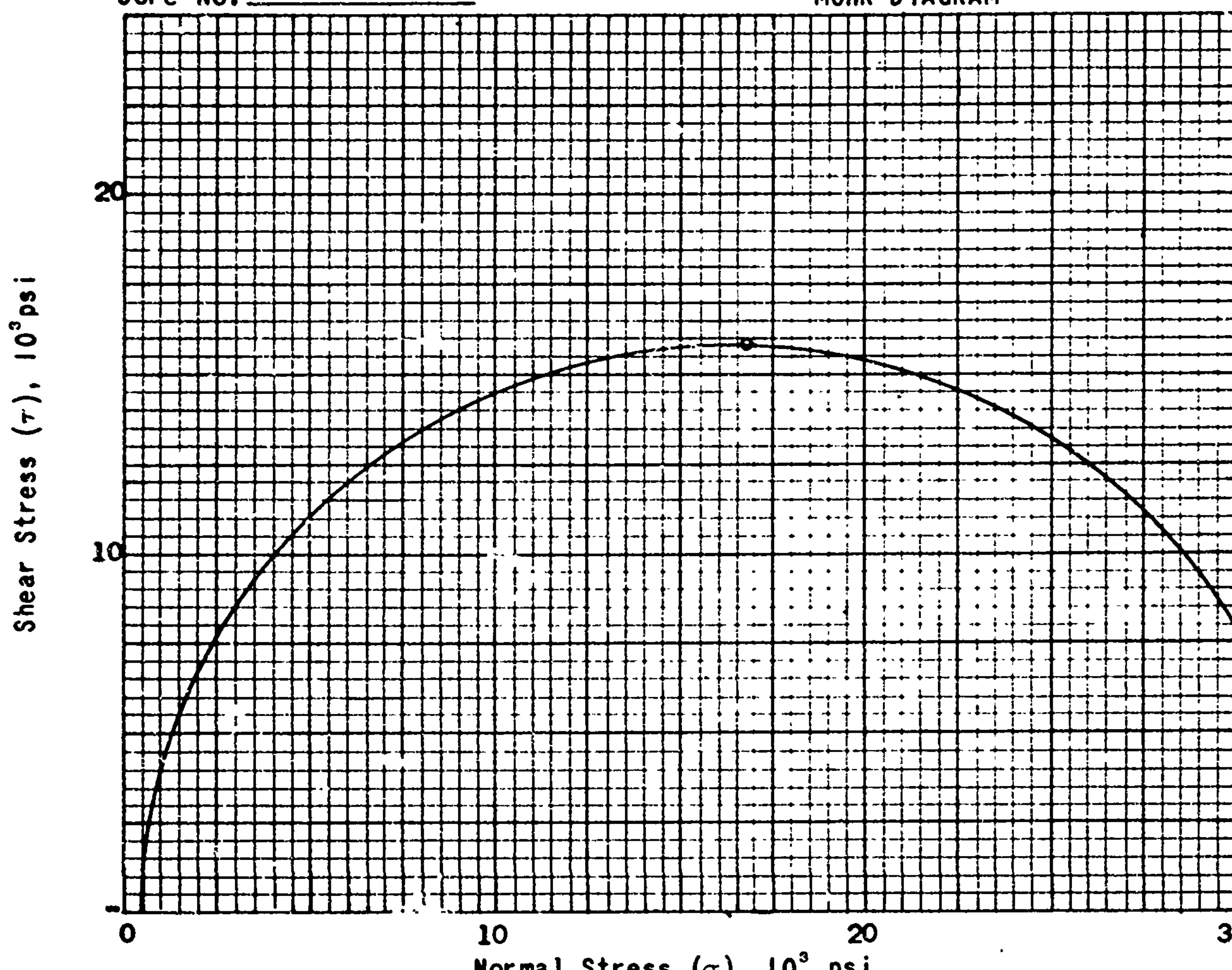
FIGURE 27

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 131

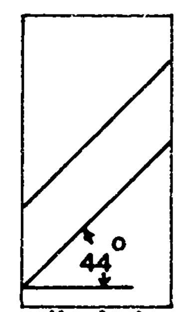
MOHR DIAGRAM



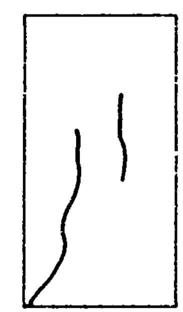
MRD Lab. No. 64/90
PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Healed Joint Plane o	Failure Plane
450	32,230	16,880	-

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Healed Joint Plane o	Failure Plane
450	32,230	15,890	-



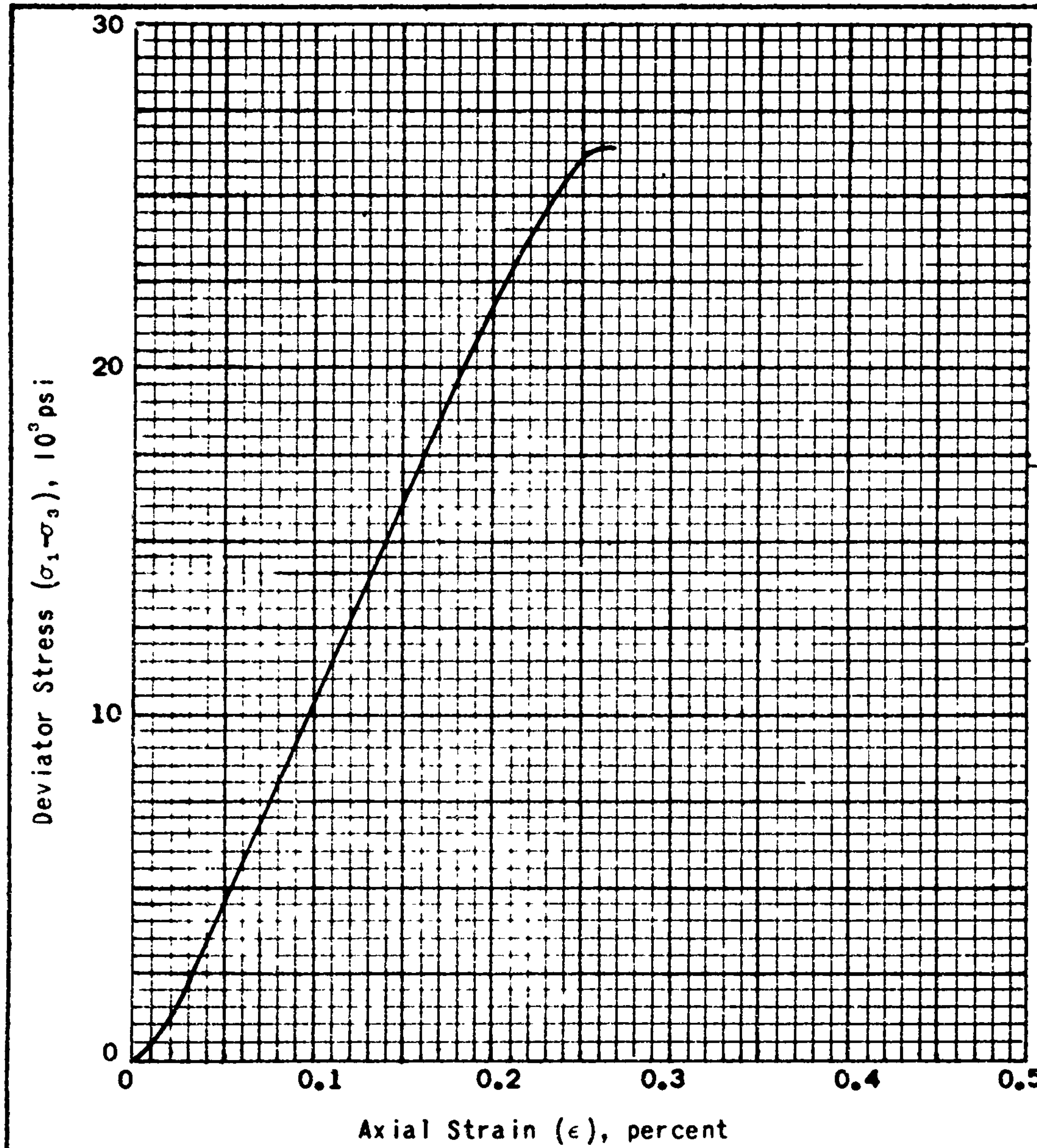
Healed Joint Plane



Failure Plane

MRD FORM
1 APR 64 738

FIGURE 28



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 151, MRD Lab. No. 64/90
Core Depth 284.1-285.4 Feet
Core Diam. 2.415 in., Core Ht. 4.58 in.
Core Weight, SSD, 982.6 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi,
①	450	11.67
②		
③		
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with fine-grained groundmass. A single feldspar crystal of 3/4-in. length occurs near one end of the core specimen. A faint well-healed fracture dips at about 55 degrees.

In triaxial compression, the core broke partially along the joint, but mainly with vertical tension fractures across the healed joint plane.

MRD FORM 1 APR 64 737

FIGURE 29

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

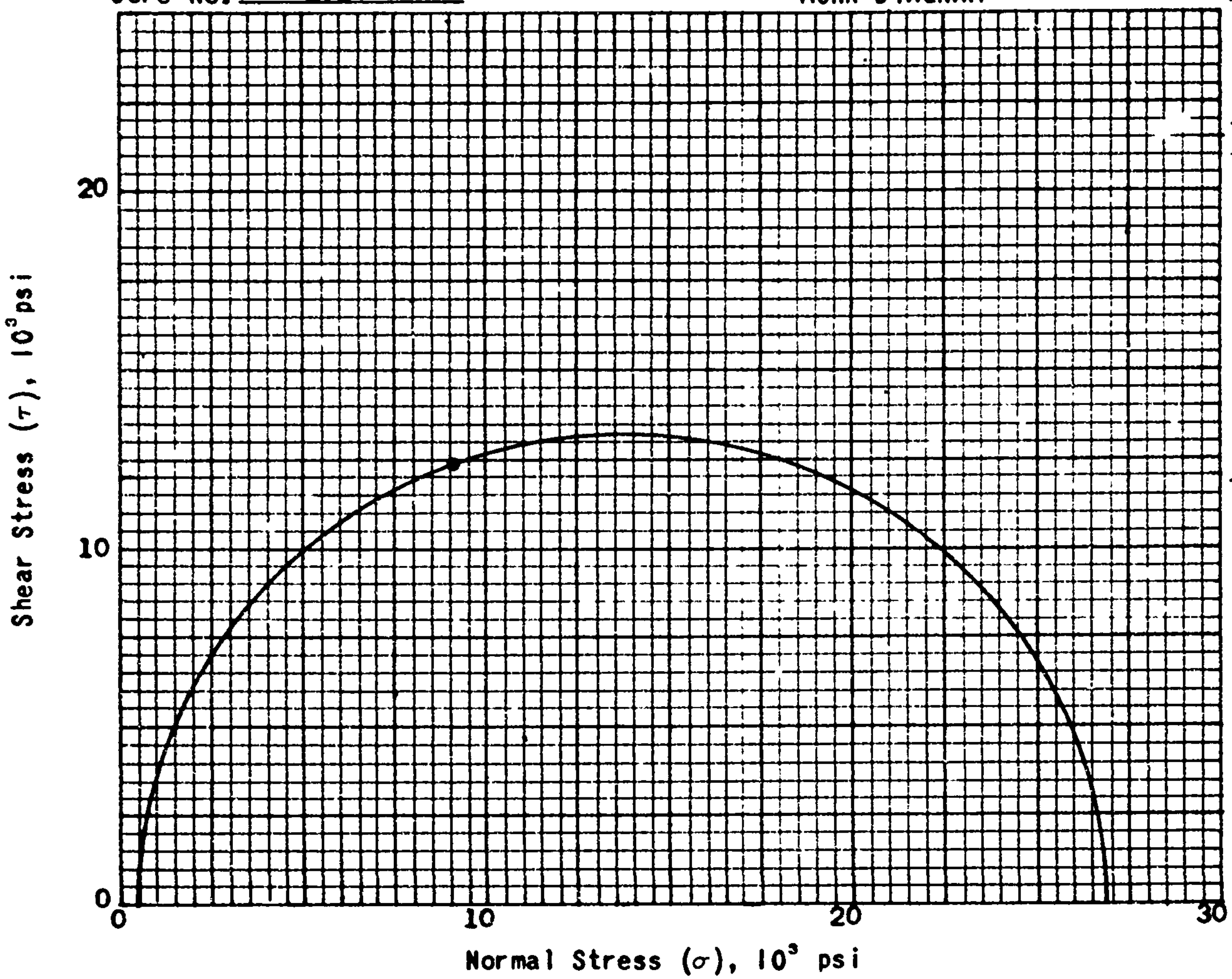
TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 151

MRD Lab. No. 64/90

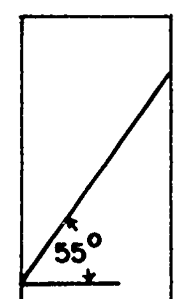
PILEDRIVER

MOHR DIAGRAM

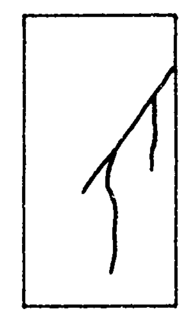


Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi: Healed Joint Plane $\circ$	Normal Stress (σ), psi: Failure Plane
450	26,830	9,130	-

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi: Healed Joint Plane $\circ$	Shear Stress (τ), psi: Failure Plane
450	26,830	12,400	-



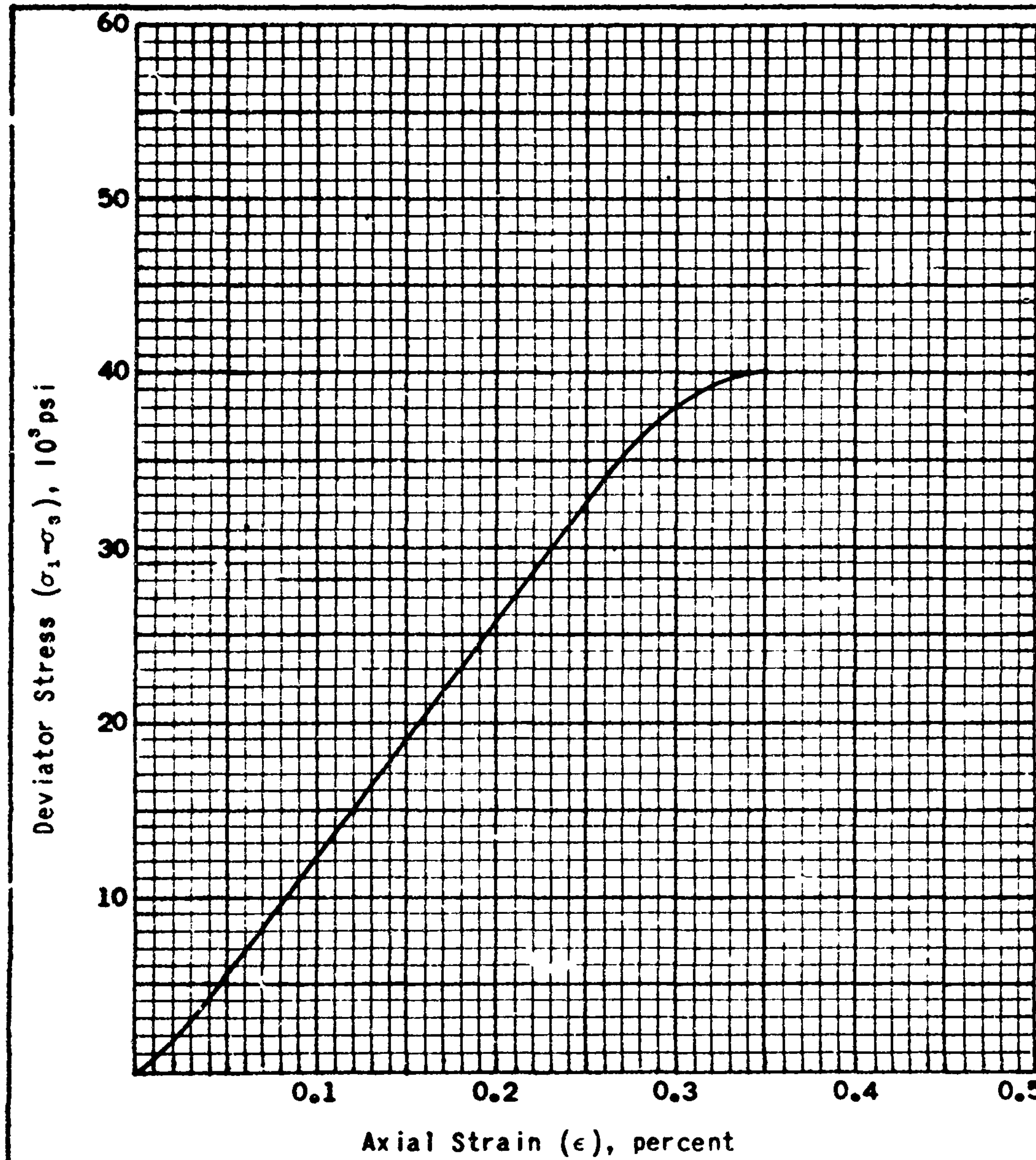
Healed Joint Plane



Failure Plane

MRD FORM 1 APR 64 738

FIGURE 30



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 138, MRD Lab. No. 64/90
Core Depth 732.9-734.7 Feet
Core Diam. 2.412 in., Core Ht. 4.87 in.
Core Weight, SSD, 976.9 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6psi,
①	450	13.64
②		
③		
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. A few scattered crystals of pink feldspar of 1/2-in. length occur throughout the core specimen. A well-healed fracture containing abundant pyrite dips about 61 degrees.

In triaxial compression, the core broke essentially with vertical tension fractures across the healed joint plane.

MRD FORM
1 APR 64 737

FIGURE 31

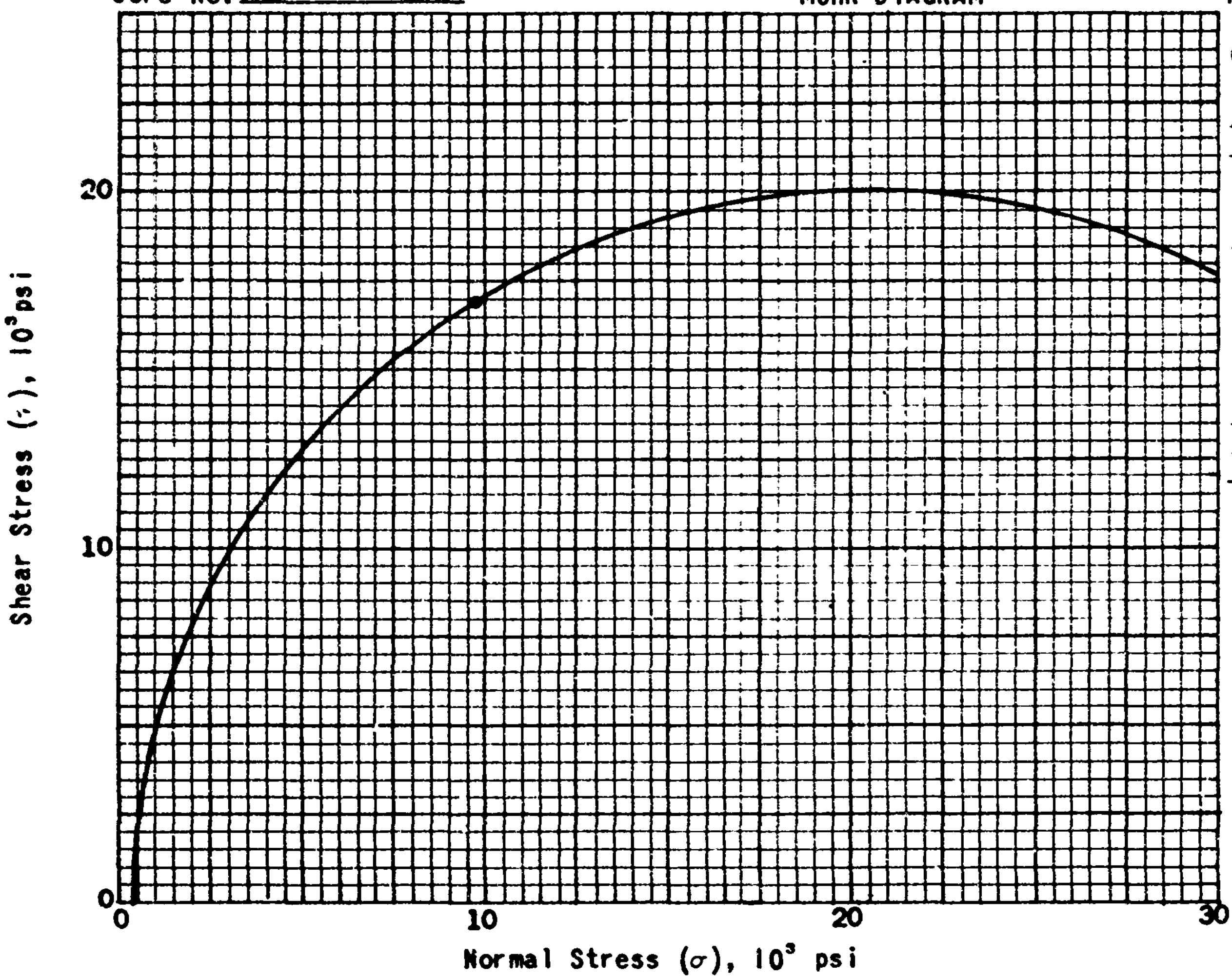
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 138

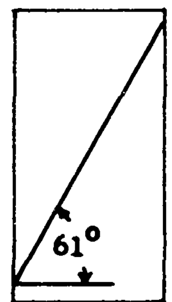
MRD Lab. No. 64/90
PILEDRIVER

MOHR DIAGRAM

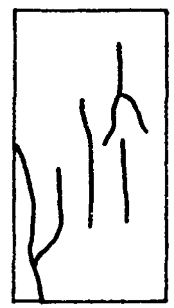


Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi: Healed Joint Plane σ	Normal Stress (σ), psi: Failure Plane
450	40,450	9,850	-

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi: Healed Joint Plane ϕ	Shear Stress (τ), psi: Failure Plane
450	40,450	16,960	-



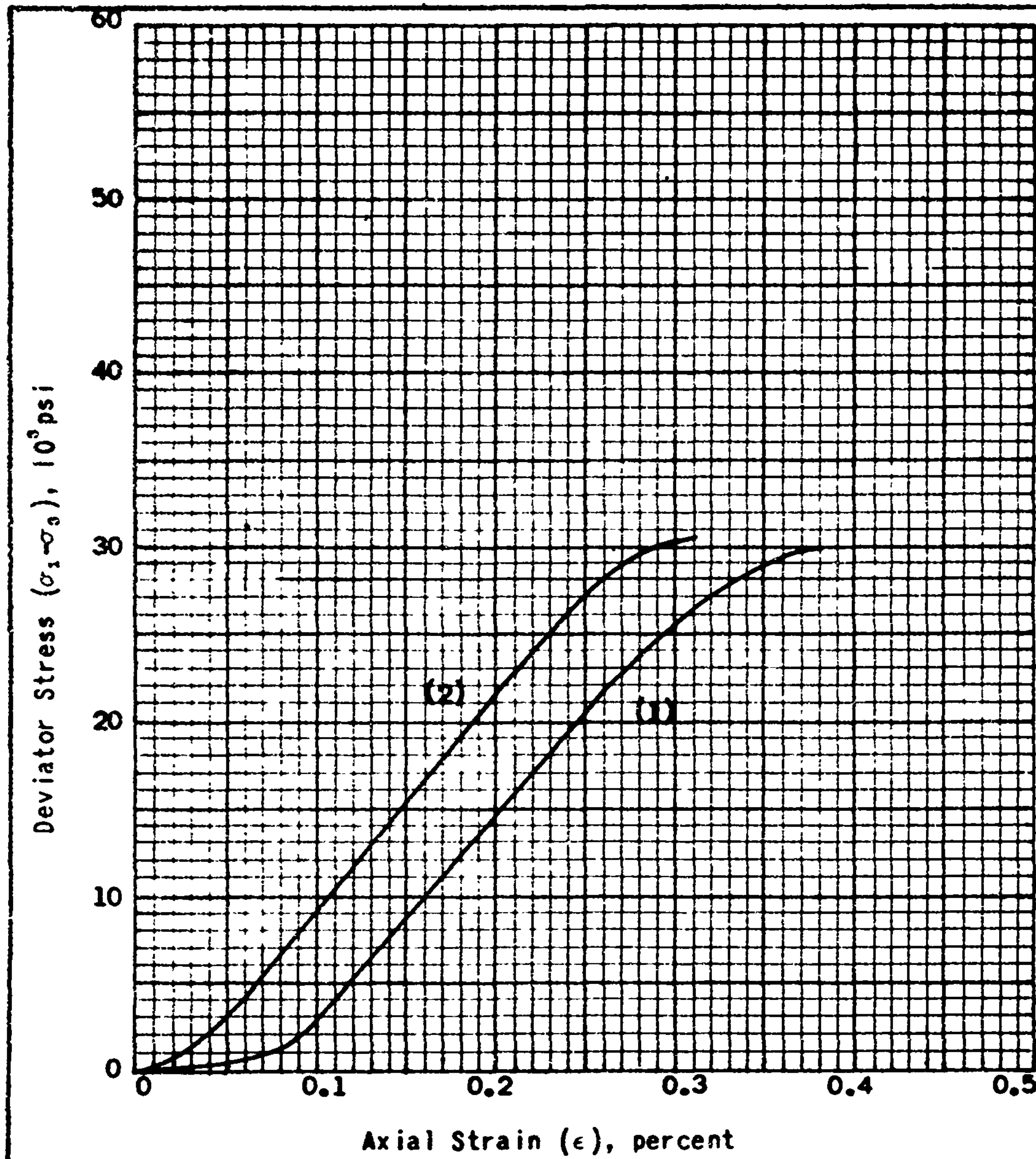
Healed Joint Plane



Failure Plane

MRD FORM 1 APR 64 738

FIGURE 32



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 159, MRD Lab. No. 64/90
Core Depth 324.0-325.0 feet
Core Diam. 2.402 in., Core Ht. 4.85 in.
Core Weight, SSD, 963.8 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi,
①	450	11.82
②	1,350	12.50
③		
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with fine-to medium-grained groundmass. No large feldspar phenocrysts were present in the core specimen. A well-healed joint filled with quartz, feldspar, and calcite dips at about 64 degrees.

In triaxial compression, the core broke essentially along the healed joint plane. Slight granulation of mineral grains and the development of slickensides were noted on the joint plane surfaces after slippage with the second stage confining pressure.

MRD FORM
1 APR 64 737

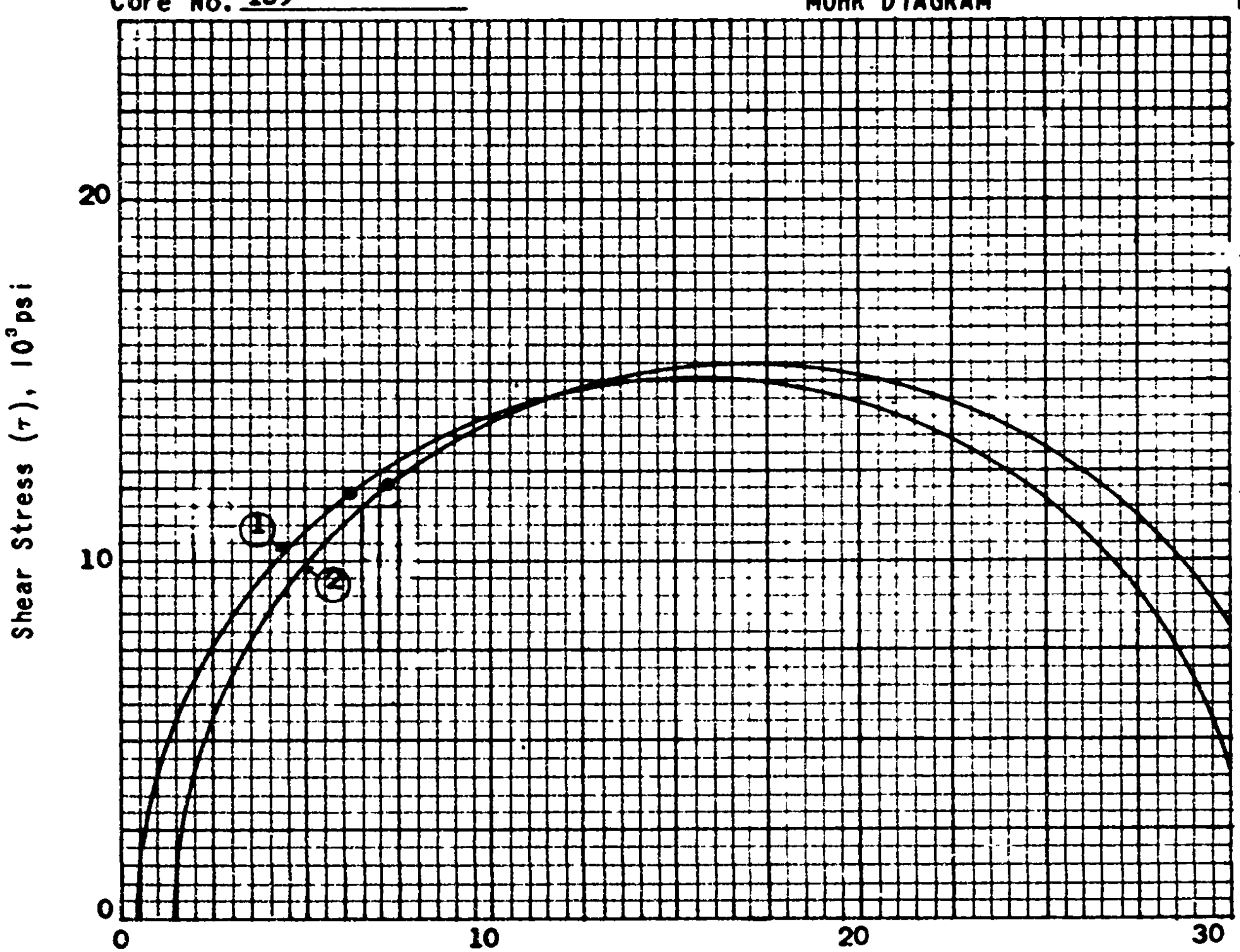
FIGURE 33

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 159

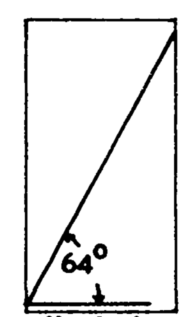
MOHR DIAGRAM



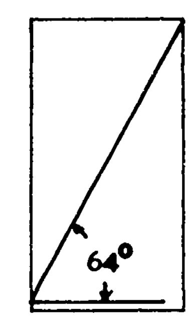
MRD Lab. No. 64/90
PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi: Healed Joint Plane ○	Normal Stress (σ), psi: Failure Plane ○
(1) 450	30430	6,210	6,210
(2) 1350	32120	7,260	7,260

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi: Healed Joint Plane ○	Shear Stress (τ), psi: Failure Plane ○
(1) 450	30430	11,810	11,810
(2) 1350	32120	12,120	12,120



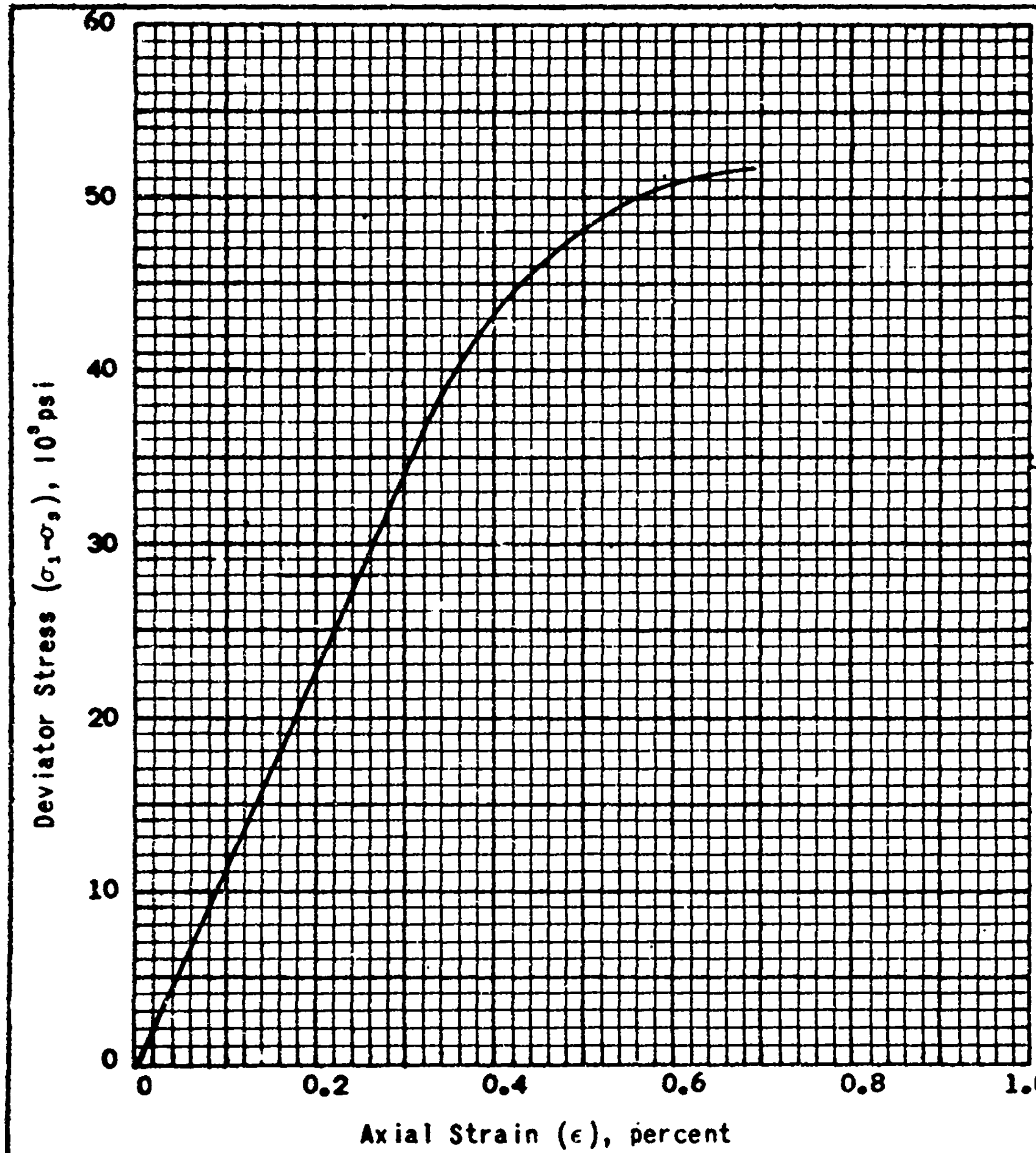
Healed Joint Plane



Failure Plane

MRD FORM 1 APR 64 738

FIGURE 34



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 155, MRD Lab. No. 64/90
Core Depth 614.9-615.9 feet
Core Diam. 2.390 in., Core Ht. 4.84 in.
Core Weight, SSD, 947.4 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi,
①	1,350	11.36
②		
③		
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. A few feldspar phenocrysts of 1-in. length occur in one end of the core specimen. A well healed fracture filled with feldspar and pyrite dips about 51 degrees. Other small vertical fractures filled with pyrite occur in one end of the core.

In triaxial compression, the core broke partially in shear and with tension fractures across the healed joint plane.

MRD FORM
1 APR 64 737

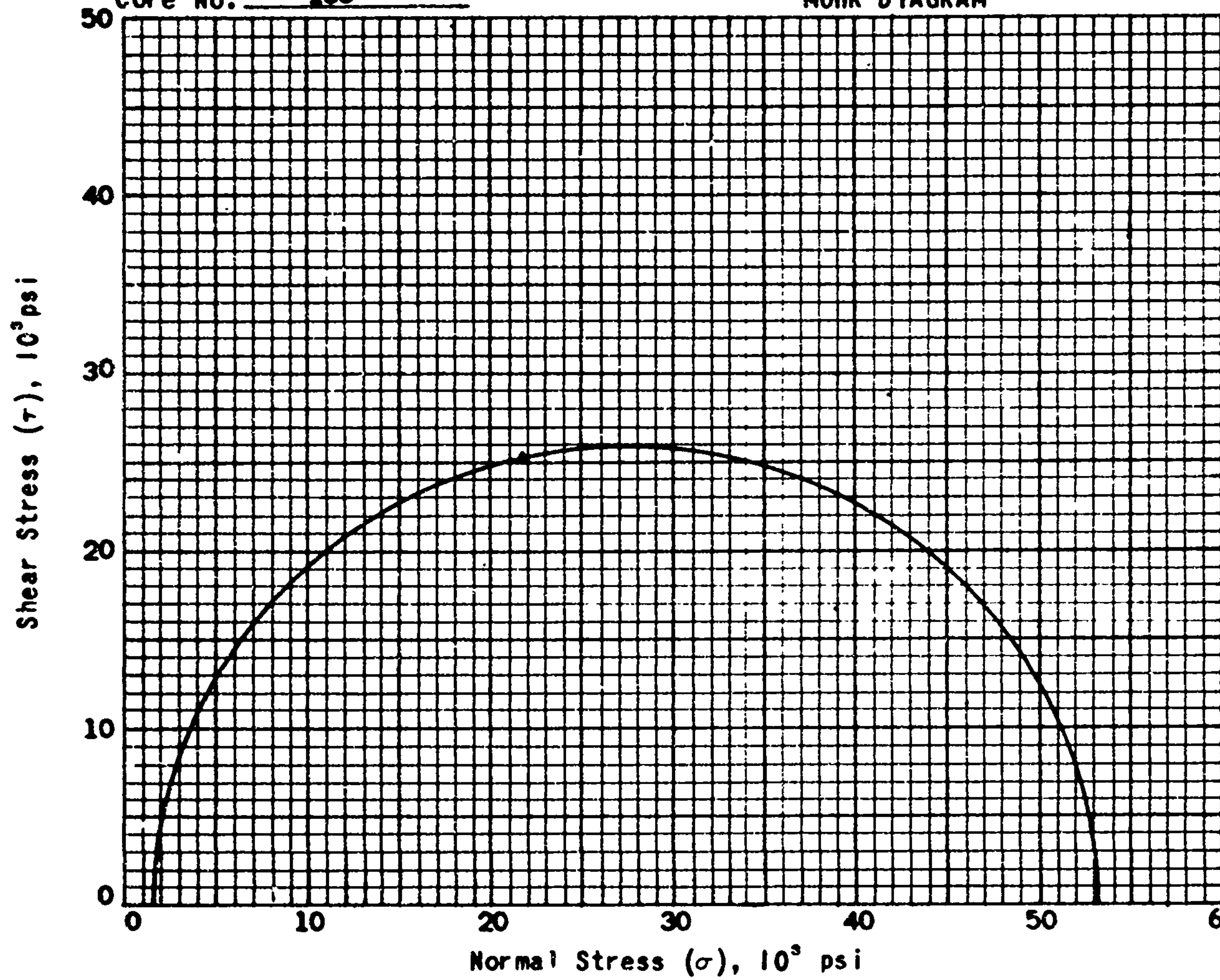
FIGURE 35

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 155

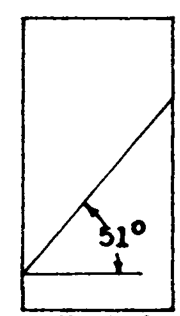
MOHR DIAGRAM



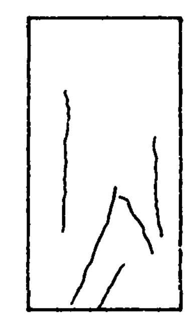
MRD Lab. No. 64/90
PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi: Healed Joint Plane △	Normal Stress (σ), psi: Failure Plane
1,350	53,330	21,930	-

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi: Healed Joint Plane	Shear Stress (τ), psi: Failure Plane
1,350	53,330	25,420	-



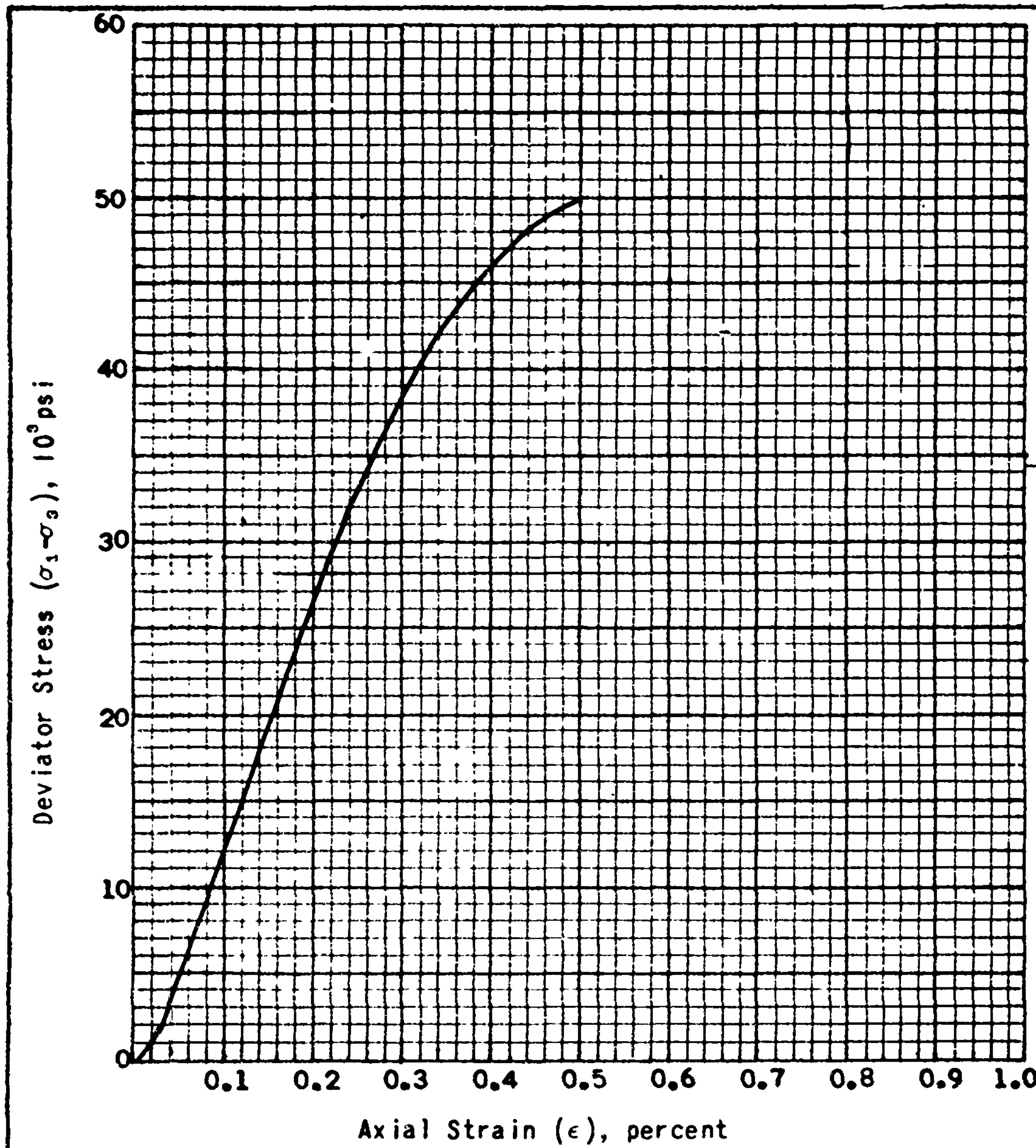
Healed Joint Plane



Failure Plane

MRD FORM
1 APR 64 738

FIGURE 36



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 134, MRD Lab. No. 64/90
Core Depth 605.6-606.7 feet
Core Diam. 2.396 in., Core Ht. 4.87 in.
Core Weight, SSD, 964.3 gm.

Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6psi,
① 1350	14.00
②	
③	
④	

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with fine to medium-grained groundmass. One large feldspar crystal of 1-in. length occurs in the central section of the core along the healed joint, another lies in an end section. The healed joint is outlined in part by pyrite.

In triaxial compression, the core broke essentially with vertical tension fractures across the healed joint plane.

MRD FORM 1 APR 64 737

FIGURE 37

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

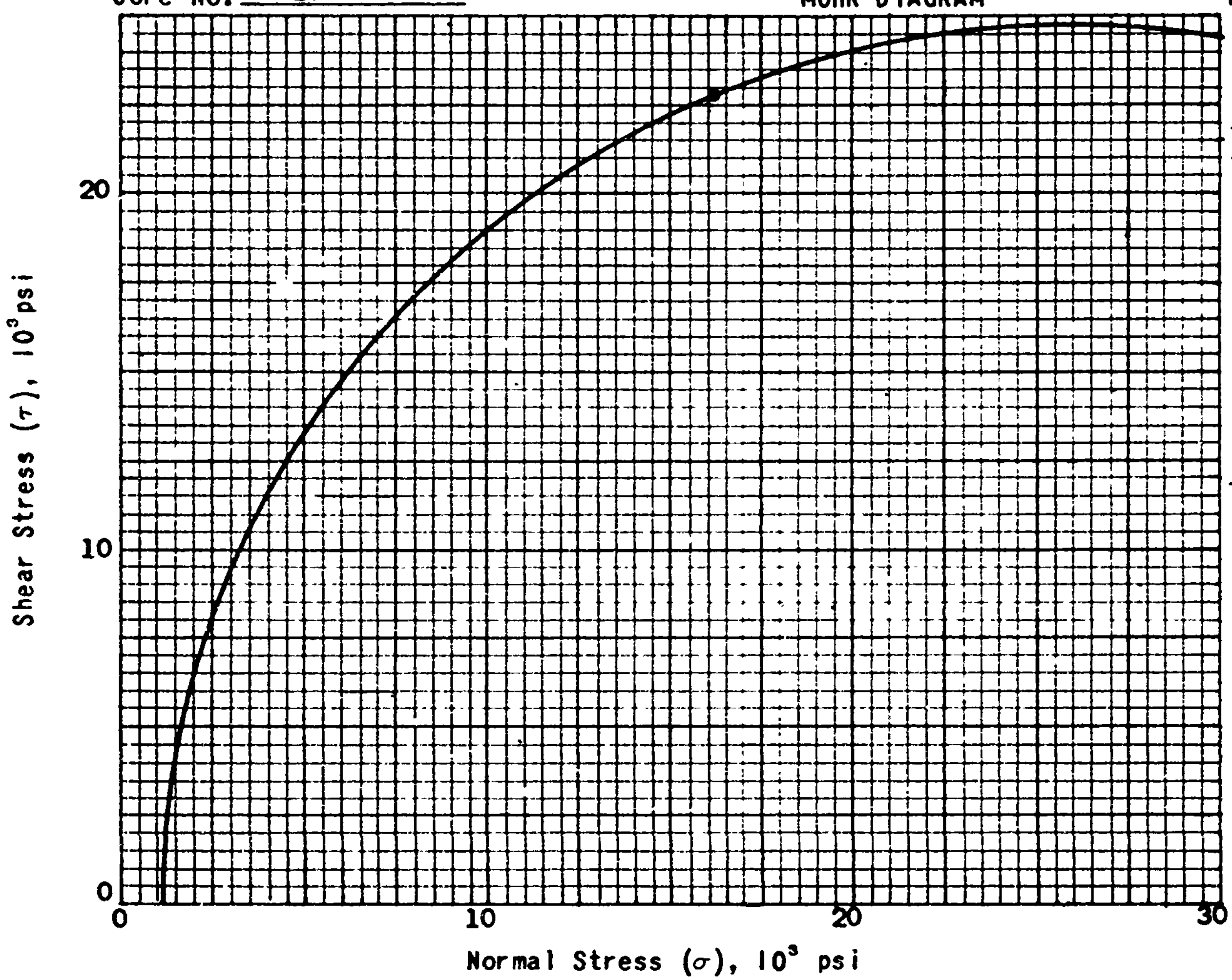
TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 134

MRD Lab. No. 64/90

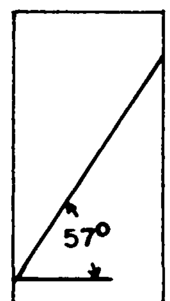
PILEDRIVER

MOHR DIAGRAM

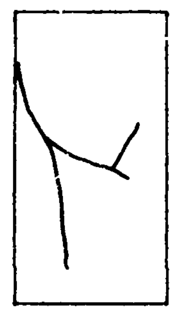


Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi: Healed Joint Plane	Normal Stress (σ), psi: Failure Plane
1350	51,000	16,100	-

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi: Healed Joint Plane	Shear Stress (τ), psi: Failure Plane
1350	51,000	22,690	-



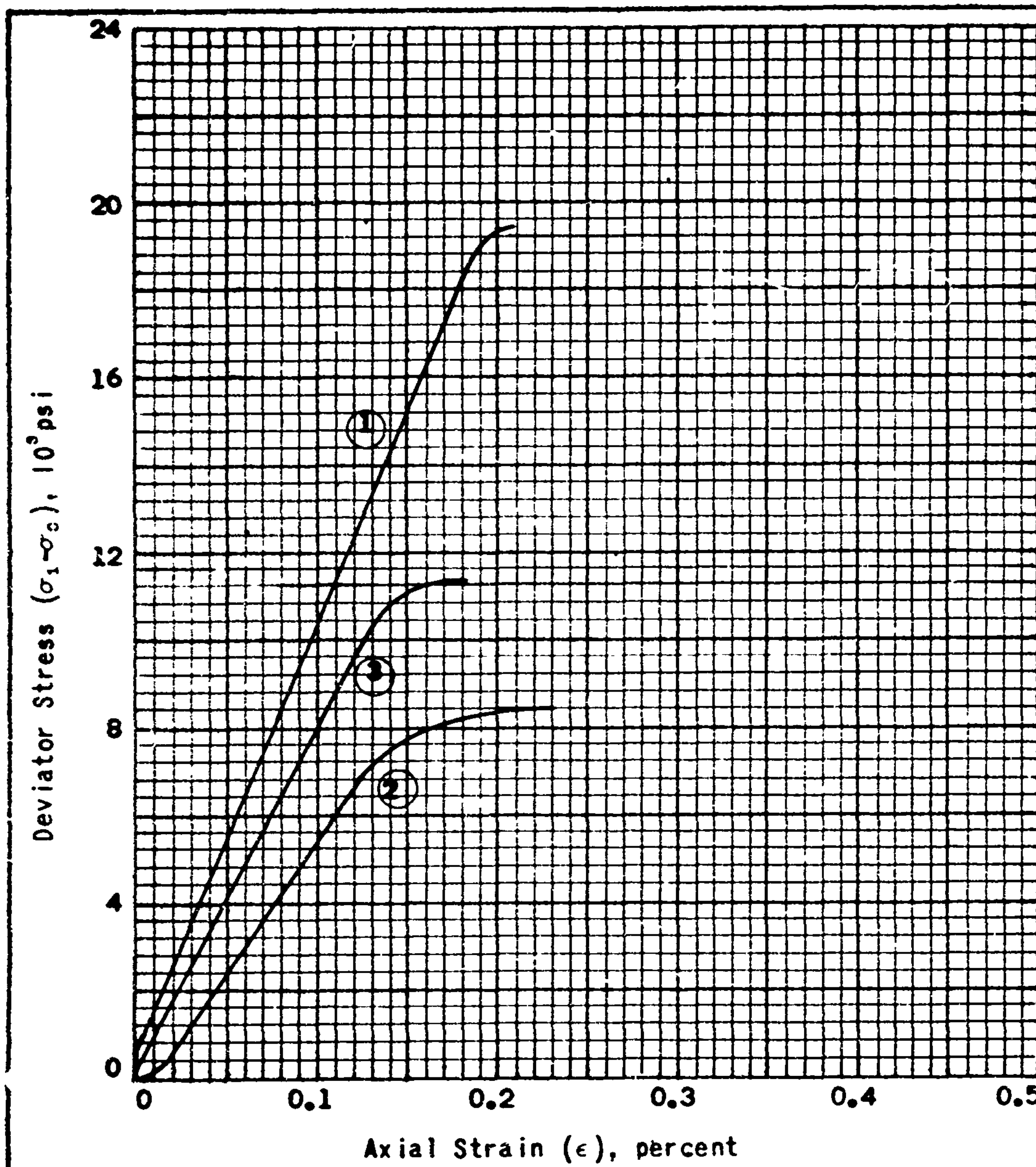
Healed Joint Plane



Failure Plane

MRD FORM 1 APR 64 738

FIGURE 38



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 153, MRD Lab. No. 64/90
Core Depth 286.6-287.7 feet
Core Diam. 2.420 in., Core Ht. 4.83 in.
Core Weight, SSD, 974.1 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6psi,
①	1,350	10.00
②	3,000	6.45
③	6,000	8.18
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with fine-grained groundmass. Several large feldspar crystals of ½-in. length occur near one end of the core specimen. A weakly cemented joint dips at about 64 degrees.

In triaxial compression, the core broke along the healed joint plane. With increased confining pressures, the core slid on the rough but planar joint surface. Slight granulation of mineral grains and faint slickensides were observed along the joint plane surfaces.

MRD FORM 1 APR 64 737

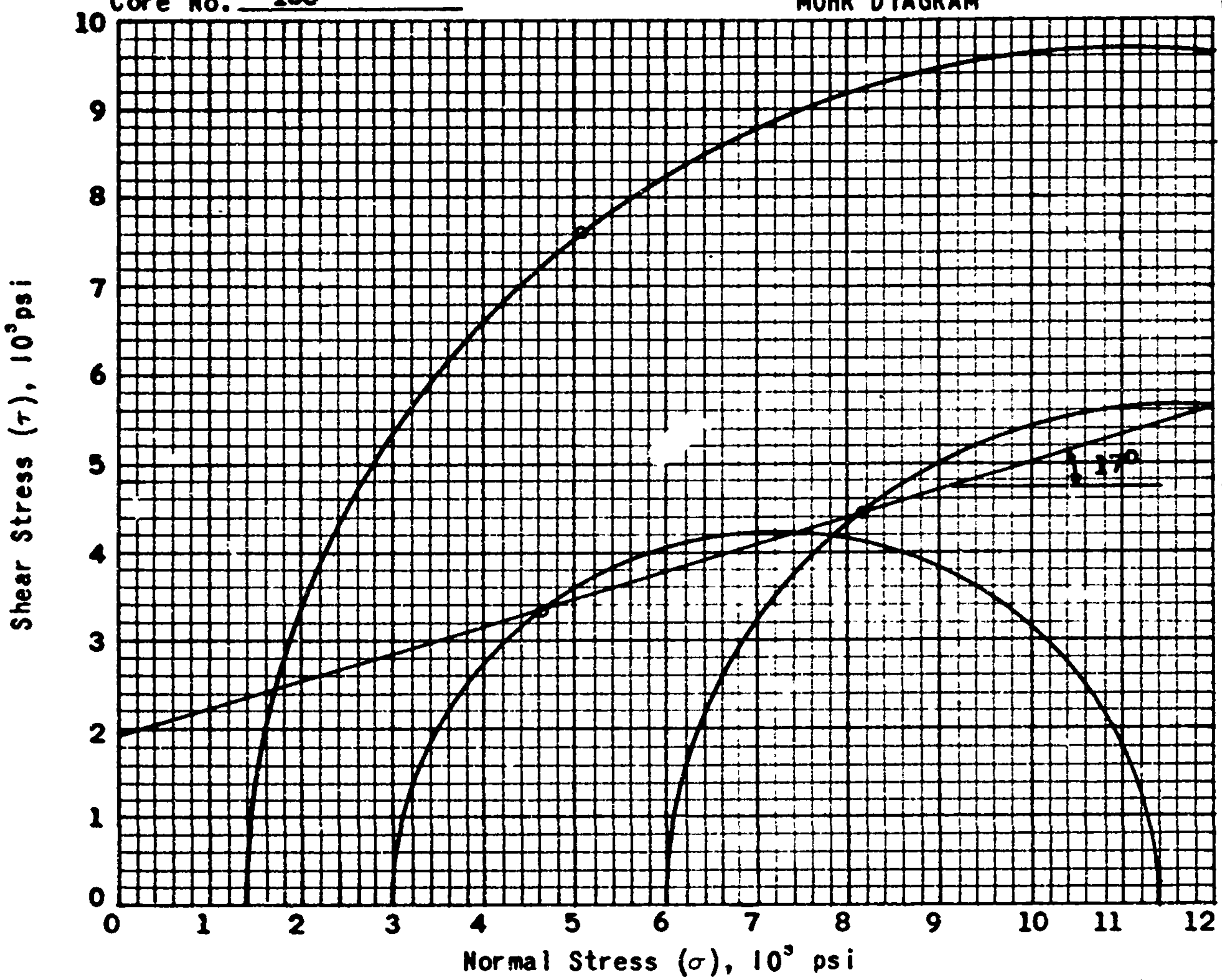
FIGURE 39

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 153

MOHR DIAGRAM

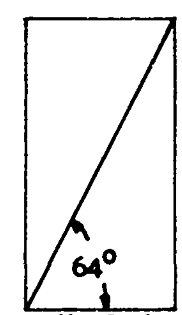


MRD Lab. No. 64/90

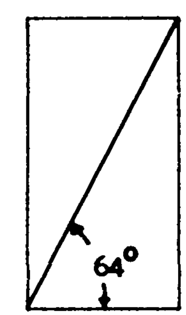
PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Healed Joint Plane o	Failure Plane o
1,350	20,760	5,080	5,080
3,000	11,430	4,620	4,620
6,000	17,220	8,150	8,150

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Healed Joint Plane o	Failure Plane o
1,350	20,760	7,650	7,650
3,000	11,430	3,320	3,320
6,000	17,220	4,420	4,420



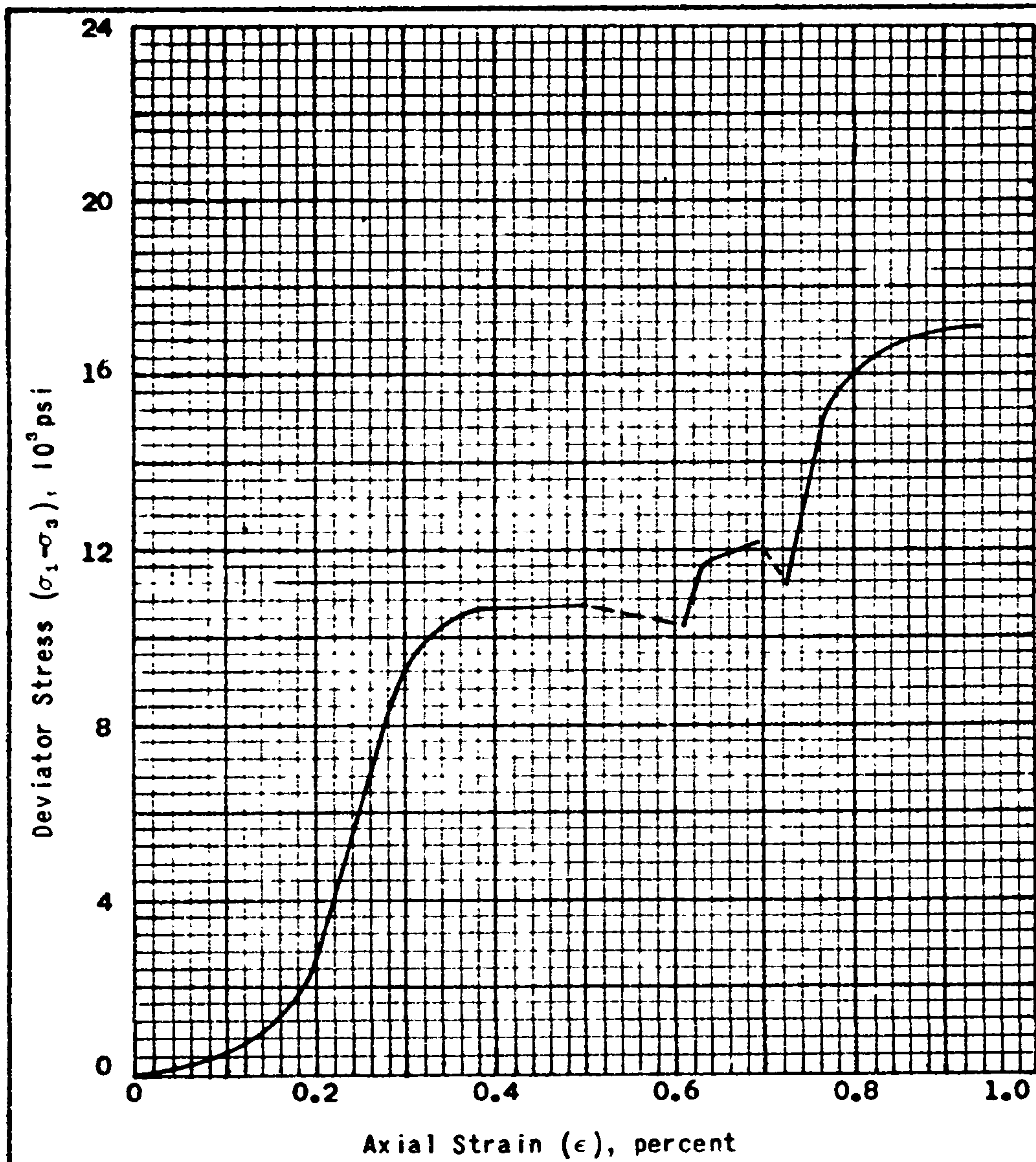
Healed Joint Plane



Failure Plane

MRD FORM 1 APR 64 738

FIGURE 40



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 120 , MRD Lab. No. 64/90
Core Depth 779.8-781.3 feet
Core Diam. 2.410 in., Core Ht. 4.81 in.
Core Weight, SSD , 947.4 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi,
①	150	6.45
②	450	7.11
③	1,350	9.26
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with fine-grained groundmass. One large feldspar crystal of 1½-in. length occurs in each of the end sections of the core specimen. A natural open joint cuts across the core near one end and dips at about 38 degrees.

In triaxial compression, multi-stage, the core slid on the joint plane with some small tension fractures cutting across it. Some granulation of mineral grains and slickensides were noted along the joint plane surfaces.

MRD FORM
1 APR 64 737

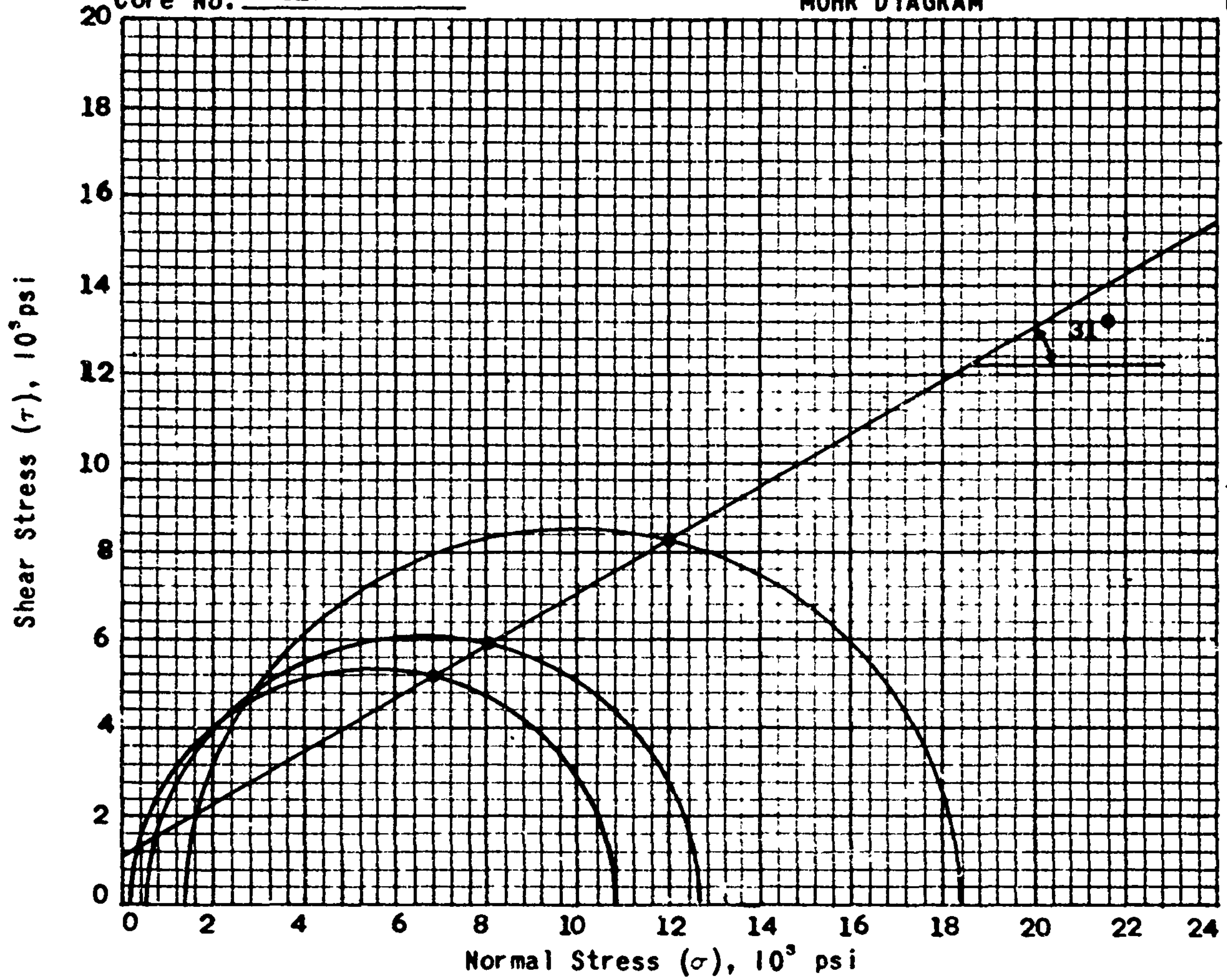
FIGURE 41

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 120 MRD Lab. No. 64/90

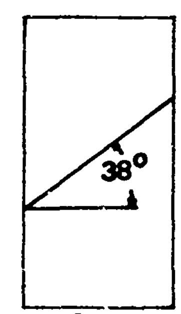
MOHR DIAGRAM



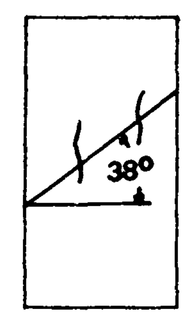
PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi: Open Joint Plane ○	Normal Stress (σ), psi: Failure Plane ○
150	10,740	6,730	6,730
450	12,640	8,020	8,020
1,350	18,430	11,960	11,960

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi: Open Joint Plane ○	Shear Stress (τ), psi: Failure Plane ○
150	10,740	5,140	5,140
450	12,640	5,910	5,910
1,350	18,430	8,280	8,280



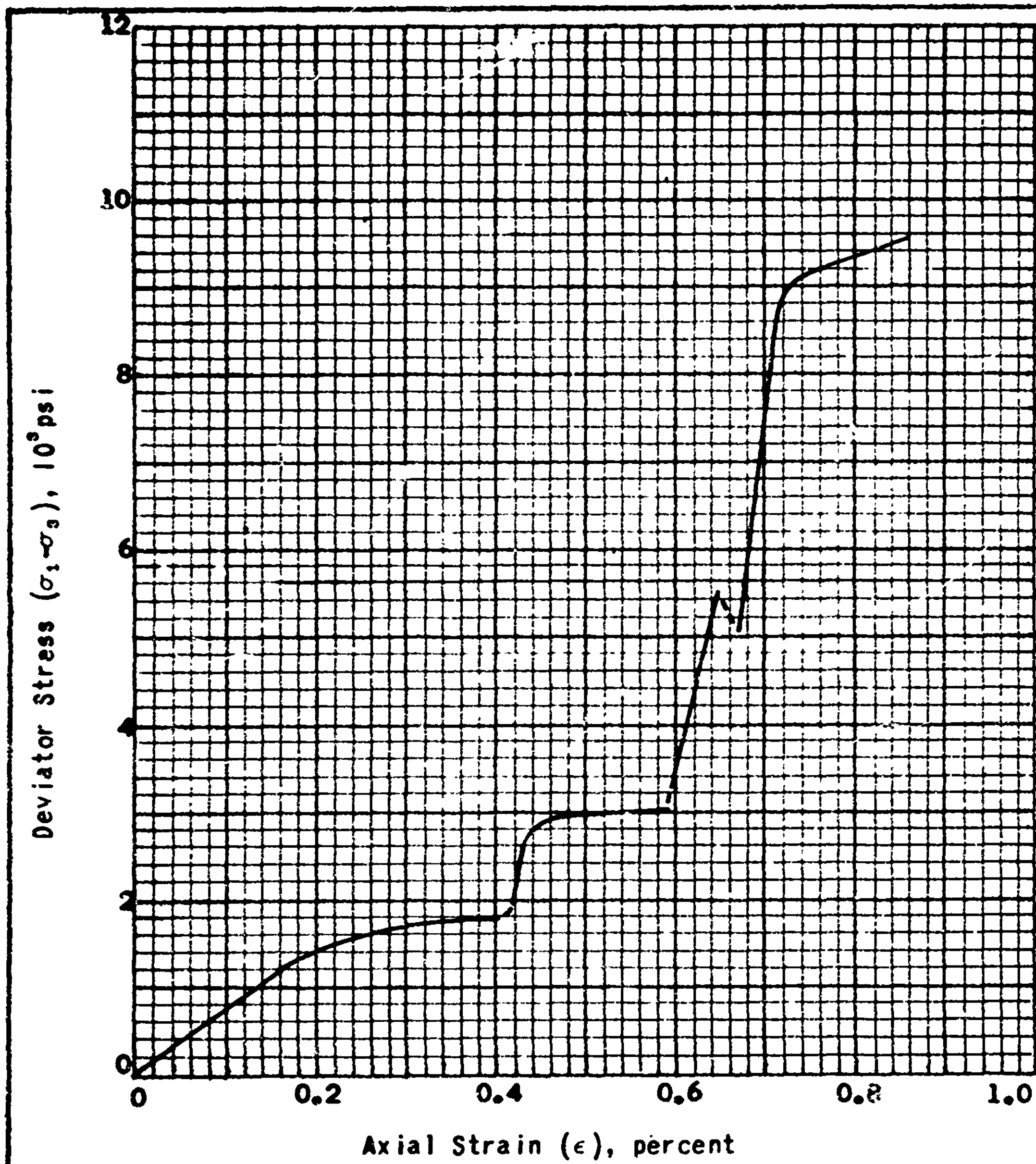
Open Joint Plane



Failure Plane

MRD FORM
1 APR 64 738

FIGURE 42



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 127, MRD Lab. No. 64/90
Core Depth 303.8-304.9 feet
Core Diam. 2.410 in., Core Ht. 4.87 in.
Core Weight, SSD , 971.6 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi,
1	150	0.75
2	450	3.25
3	1,350	4.50
4	3,000	12.00

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with fine-grained groundmass. No large feldspar crystals were present in the core. A natural open joint with a rough but planar surface dips at about 54 degrees.

In triaxial compression, multi-stage, the core slid on the joint plane. Slight granulation of mineral grains and faint slickensides were developed along parts of the joint plane surfaces.

MRD FORM
1 APR 64 737

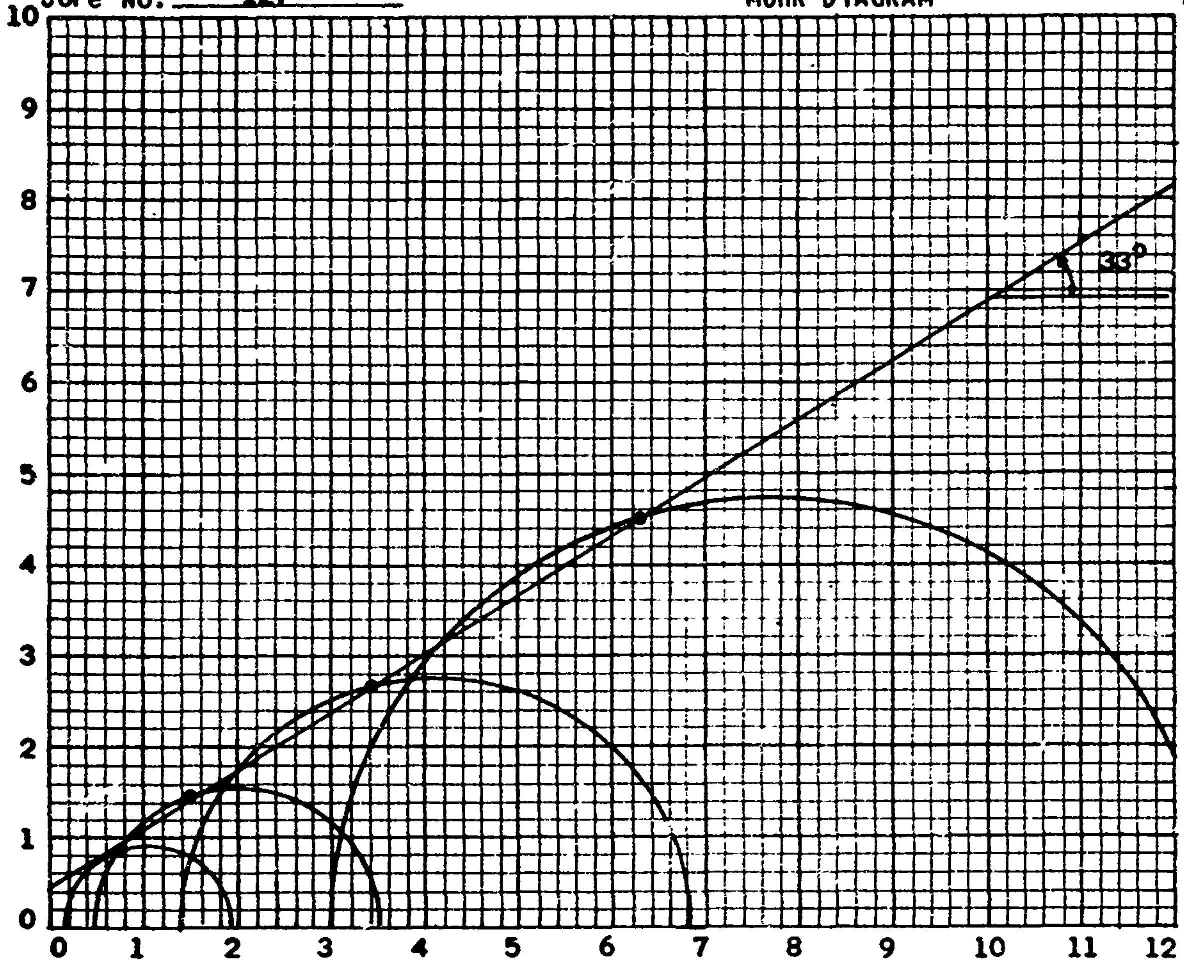
FIGURE 43

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 127

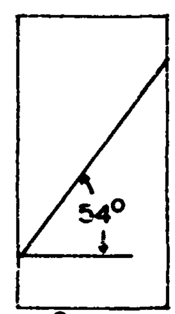
MOHR DIAGRAM



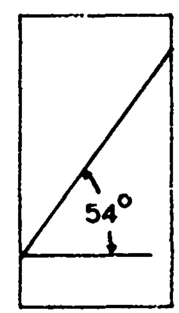
MRD Lab. No. 64/90
PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi: Open Joint Plane ○	Normal Stress (σ), psi: Failure Plane ○
150	1,930	760	760
450	3,480	1,500	1,500
1,350	6,830	3,430	3,430
3,000	12,340	6,230	6,230

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi: Open Joint Plane ○	Shear Stress (τ), psi: Failure Plane ○
150	1,930	840	840
450	3,480	1,440	1,440
1,350	6,830	2,610	2,610
3,000	12,340	4,440	4,440



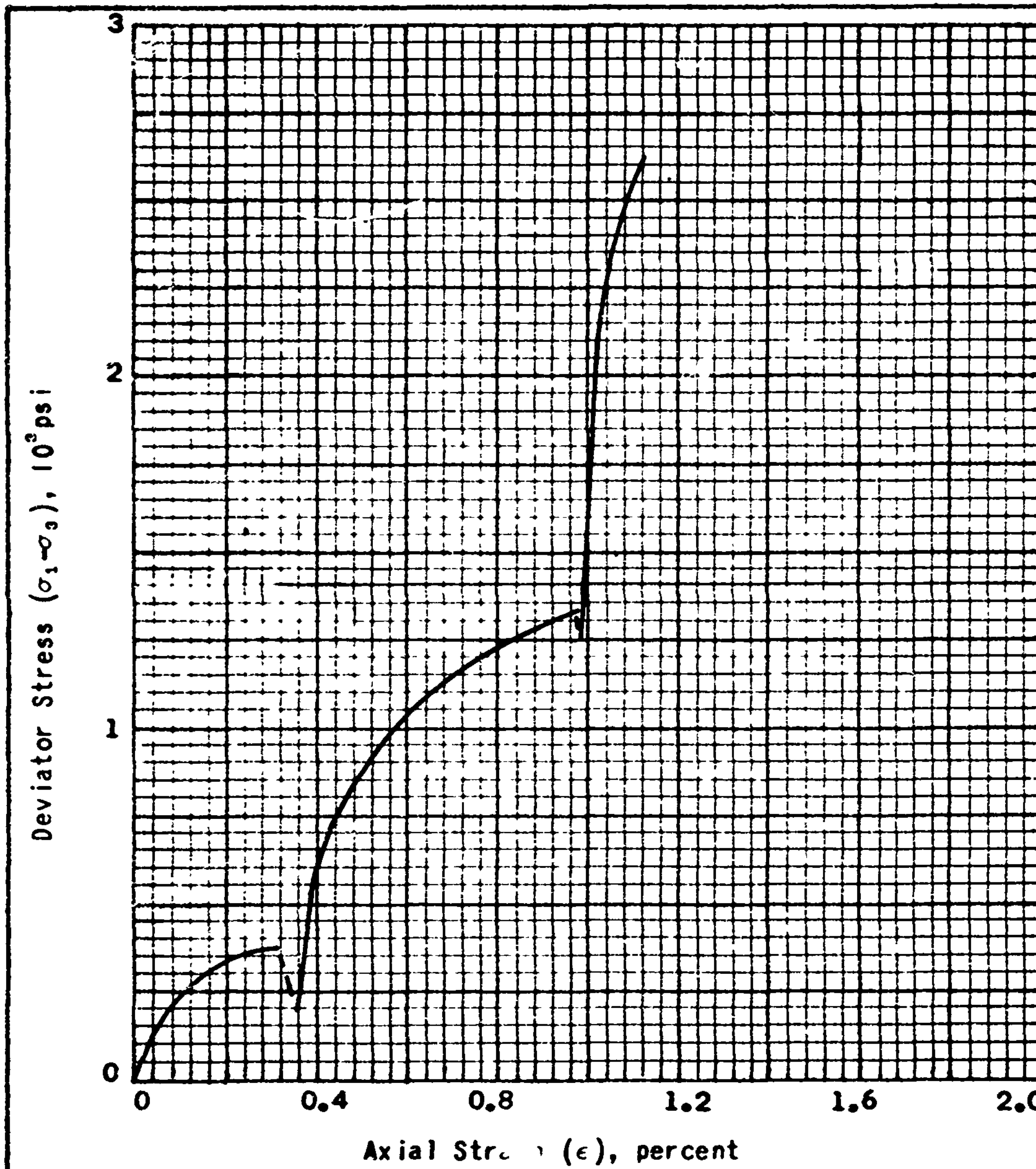
Open Joint Plane



Failure Plane

MRD FORM 1 APR 64 738

FIGURE 44



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 158 , MRD Lab. No. 64/90
Core Depth 372.2-372.9 feet
Core Diam. 2.400 in., Core Ht. 4.83 in.
Core Weight, SSD , 940.0 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi,
①	150	0.25
②	450	0.83
③	1,350	6.25
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. Two large feldspar crystals of 1½-in. length occur in the central section of the core specimen. A natural open joint with a rough, wavy surface dips at about 59 degrees.

In triaxial compression, multi-stage, the core slid on the joint plane with slight granulation of mineral grains. Slickensides were not too well developed because of surface irregularities.

MRD FORM 1 APR 64 737

FIGURE 45

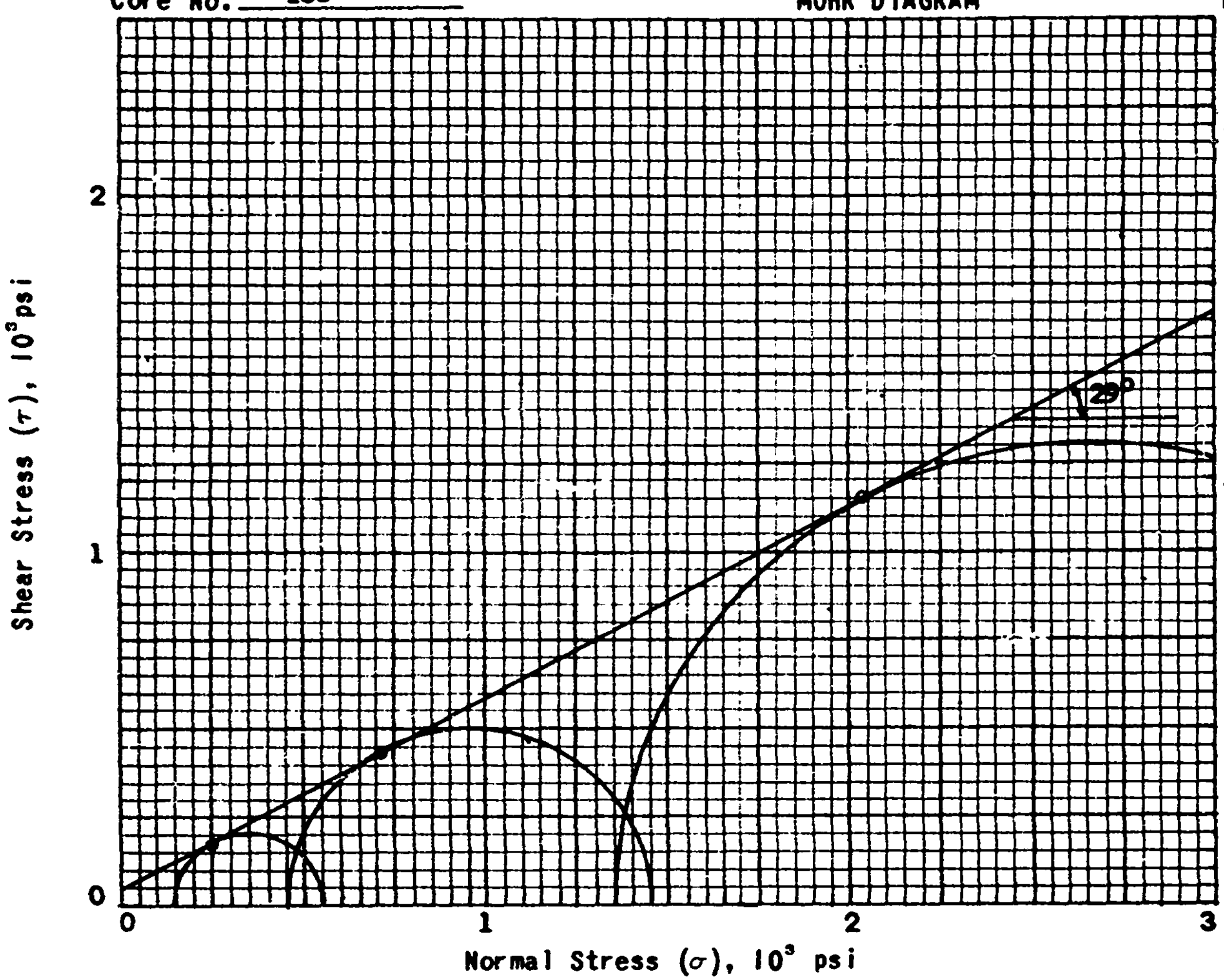
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 158

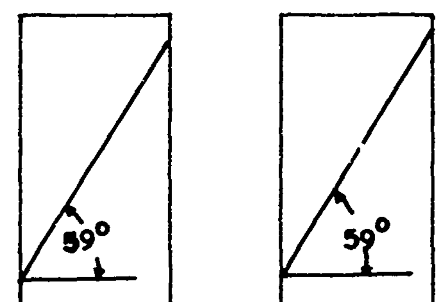
MRD Lab. No. 64/90

PILEDRIVER



Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi: Open Joint Plane ○	Normal Stress (σ), psi: Failure Plane ○
150	530	250	25[illegible]
450	1,450	720	720
1,350	3,970	2,040	2,040

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi: Open Joint Plane ○	Shear Stress (τ), psi: Failure Plane ○
150	530	170	170
450	1,450	440	440
1,350	3,970	1,160	1,160

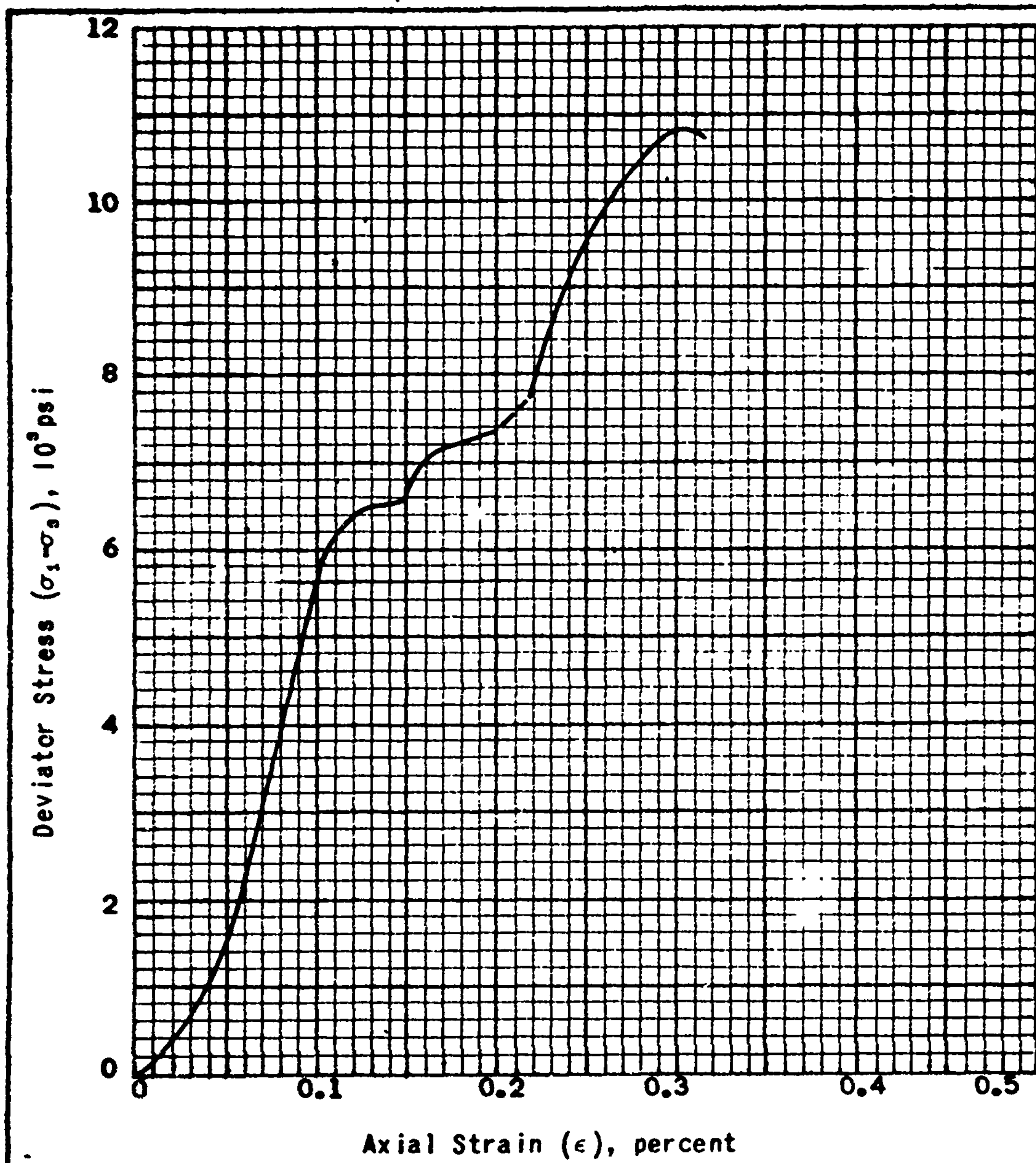


Open Joint Plane

Failure Plane

MRD FORM 1 APR 64 738

FIGURE 46



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 108 , MRD Lab. No. 64/90
Core Depth 442.6-444.0 feet
Core Diam. 2.400 in., Core Ht. 4.81 in.
Core Weight, SSD , 940.1 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6psi,
1	150	8.27
2	450	6.50
3		
4		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. No large feldspar crystals are present in the core specimen. A pair of bisecting healed joints cut the rock at about 62 degrees from the horizontal. The joints are filled with weak, water soluble minerals.

In triaxial compression, multi-stage, the core slid on one of the joint planes in part, but both sets of joints were split open.

MRD FORM 737
1 APR 64

FIGURE 47

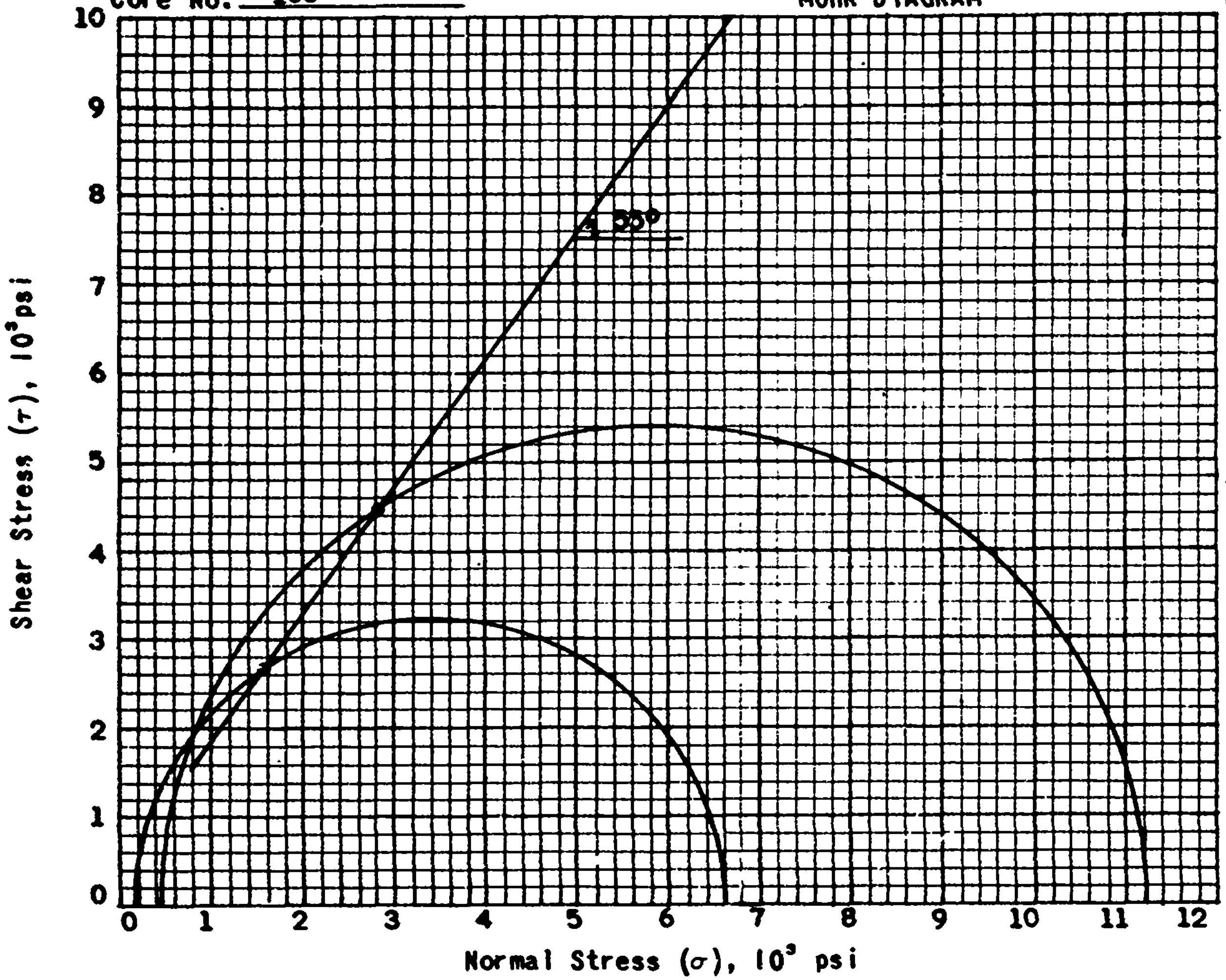
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 108

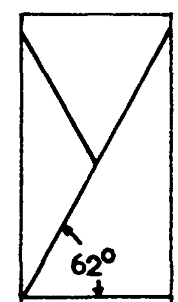
MRD Lab. No. 64/90
PILEDRIVER

MOHR DIAGRAM

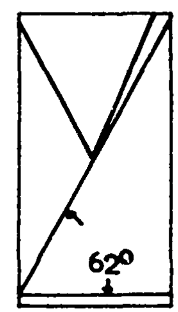


Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi: Partly Open Joint Plane ○	Normal Stress (σ), psi: Failure Plane ○
150	6,600	1,570	1,570
450	11,240	2,820	2,820

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi: Partly Open Joint Plane ○	Shear Stress (τ), psi: Failure Plane ○
150	6,600	2,670	2,670
450	11,240	4,470	4,470



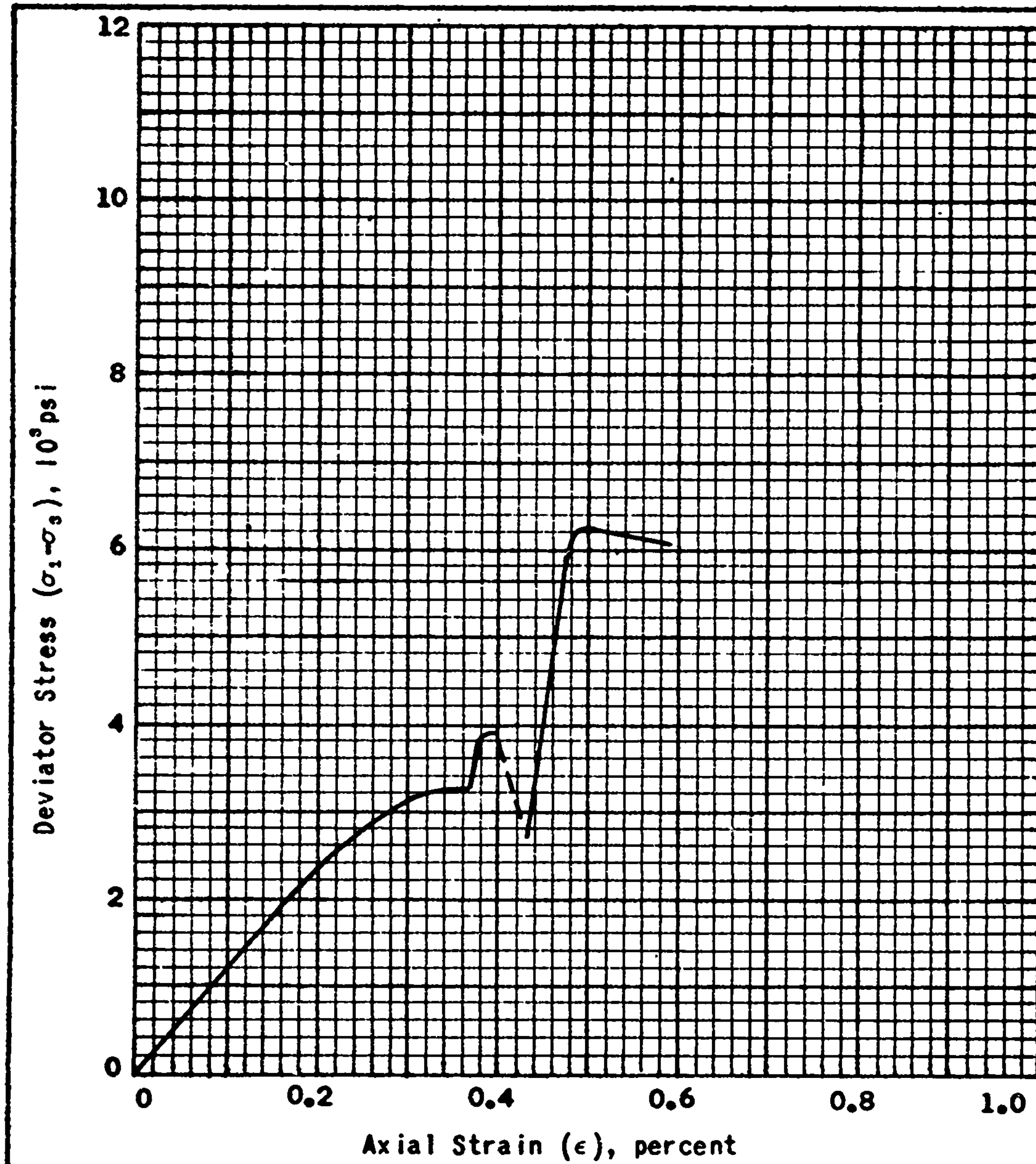
Partly Open Joint Plane



Failure Plane

MRD FORM 1 APR 64 738

FIGURE 48



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 125, MRD Lab. No. 64/90
Core Depth 561.7-563.0 feet
Core Diam. 2.400 in., Core Ht. 5.12 in.
Core Weight, SSD, 1000.0 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6psi,
①	150	2.00
②	450	3.65
③	1,350	10.00
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. No large crystals of feldspar are present in the core specimen. A natural open joint with a rough but planar surface dips at about 66 degrees.

In triaxial compression, multi-stage, the core slid on the joint plane with very little granulation of mineral grains. Some vertical tension fractures were produced probably because of irregularities on the joint plane surfaces.

MRD FORM
1 APR 64 737

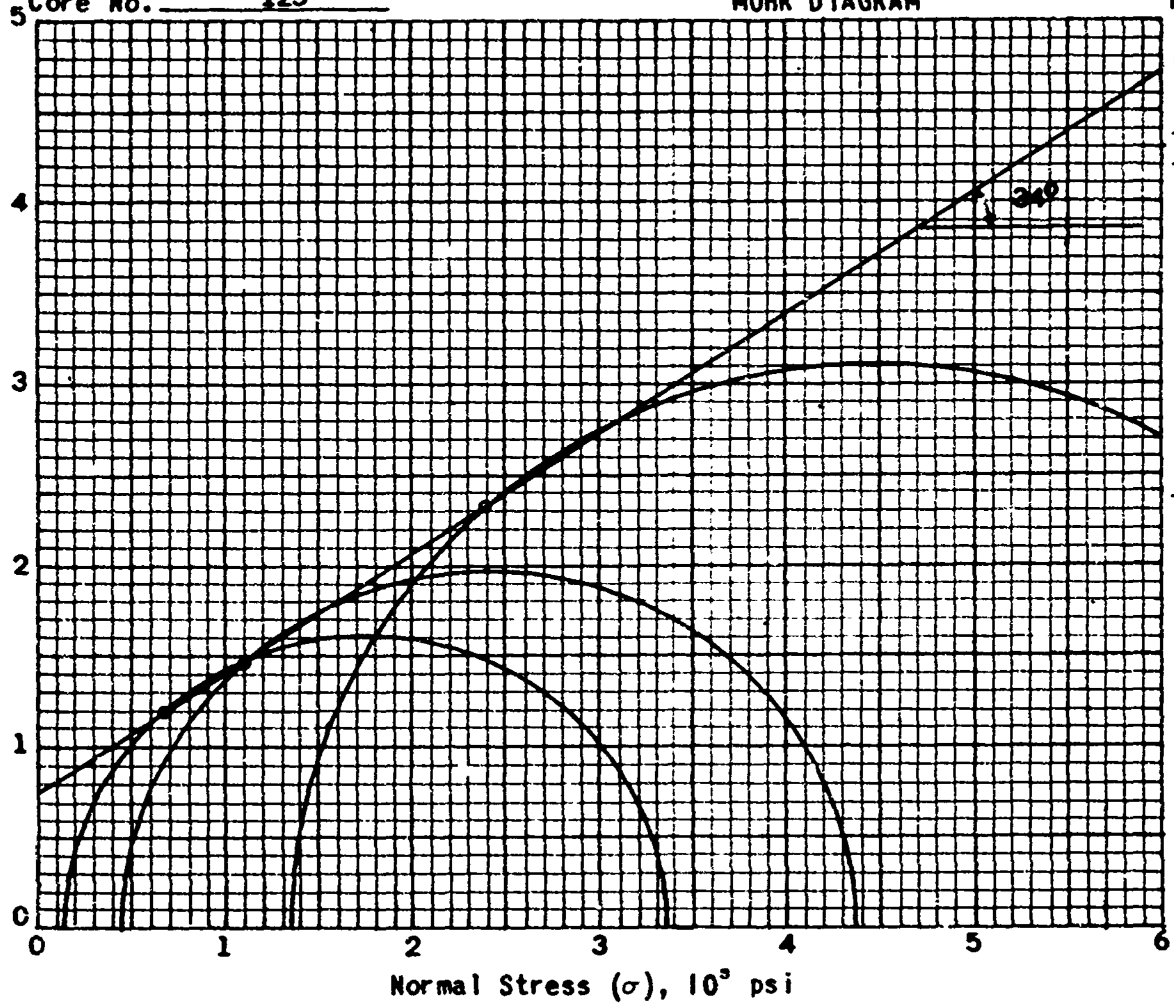
FIGURE 49

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 125

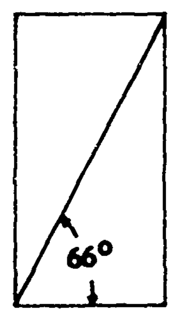
MOHR DIAGRAM



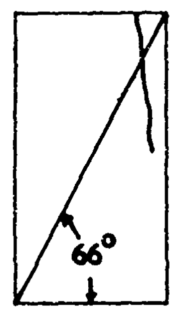
MRD Lab. No. 64/90 PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi: Open Joint Plane ○	Normal Stress (σ), psi: Failure Plane ○
150	3,360	680	680
450	4,350	1,100	1,100
1,350	7,600	2,390	2,390

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi: Open Joint Plane ○	Shear Stress (τ), psi: Failure Plane ○
150	3,360	1,200	1,200
450	4,350	1,450	1,450
1,350	7,600	2,320	2,320



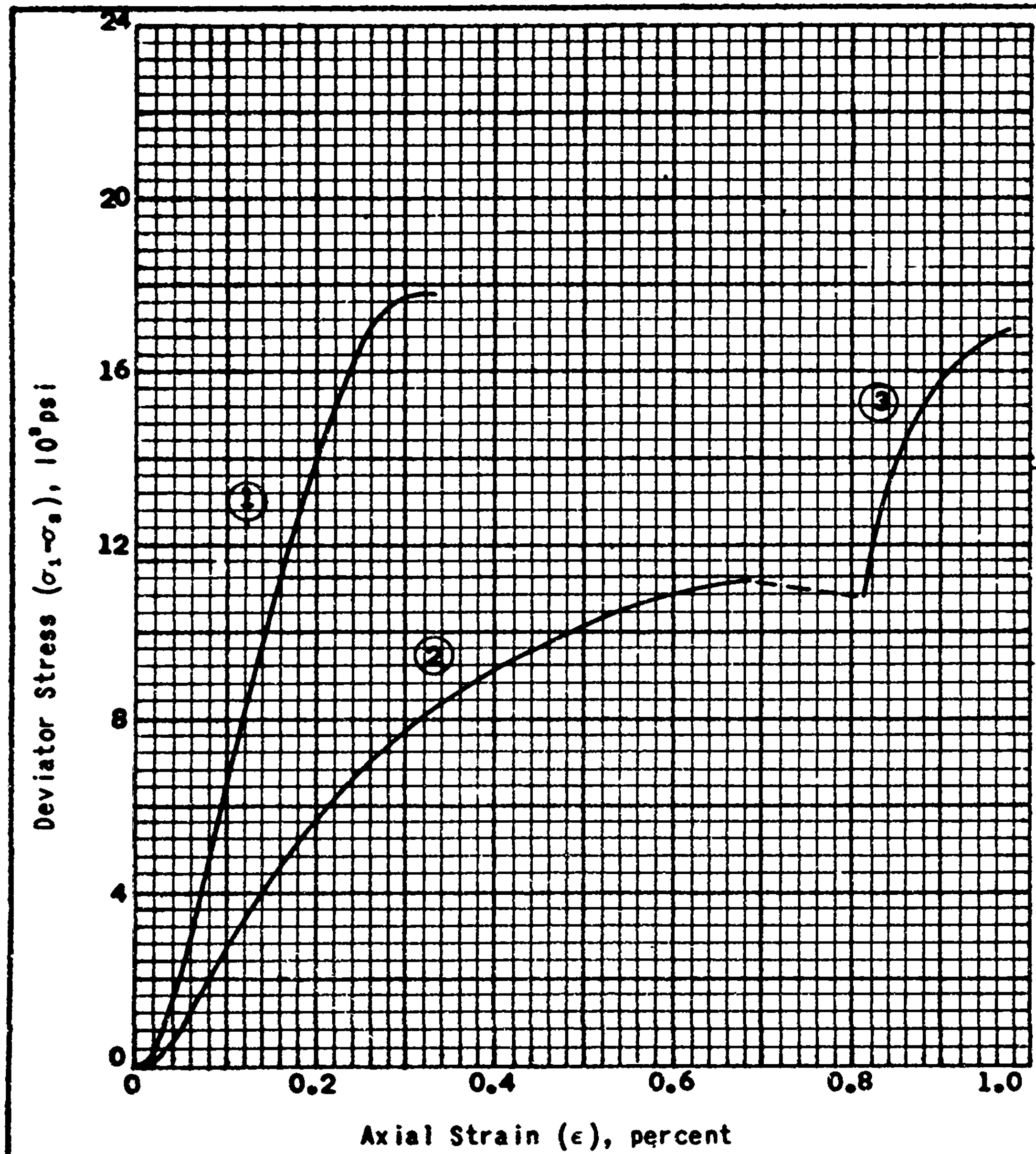
Open Joint Plane



Failure Plane

MRD FORM 1 APR 64 738

FIGURE 50



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 169, MRD Lab. No. 64/90
Core Depth 167.2-168.8 feet
Core Diam. 2.420 in., Core Ht. 4.83 in.
Core Weight, SSD, 978.9 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6psi,
①	450	7.46
②	1,350	3.25
③	3,000	7.41
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. One large feldspar crystal of 1-in. length occurs in one end of the core specimen. A natural open joint with a rough but planar surface dips at about 44 degrees.

In triaxial compression, multi-stage, the core slid on the joint plane producing a moderate amount of granulation of mineral grains and some slickensides.

MRD FORM 1 APR 64 737

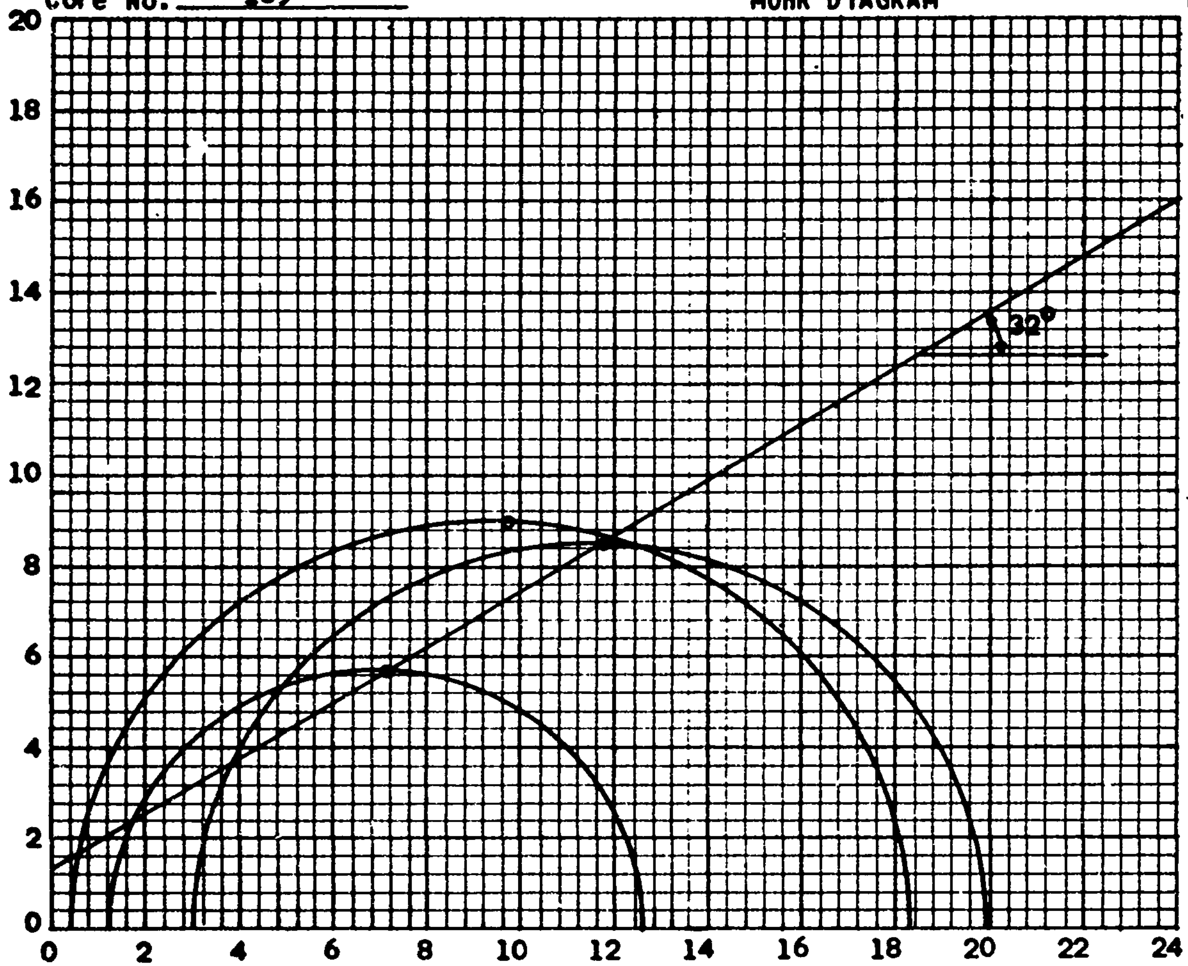
FIGURE 51

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 169

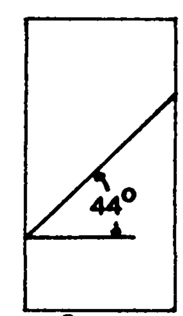
MOHR DIAGRAM



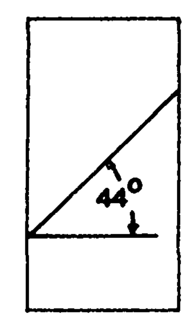
MRD Lab. No. 64/90
PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Open Joint Plane ○	Failure Plane ○
450	18,270	9,660	9,660
1,350	12,480	7,100	7,100
3,000	19,910	11,740	11,740

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Open Joint Plane ○	Failure Plane ○
450	18,270	8,910	8,910
1,350	12,480	5,570	5,570
3,000	19,910	8,460	8,460



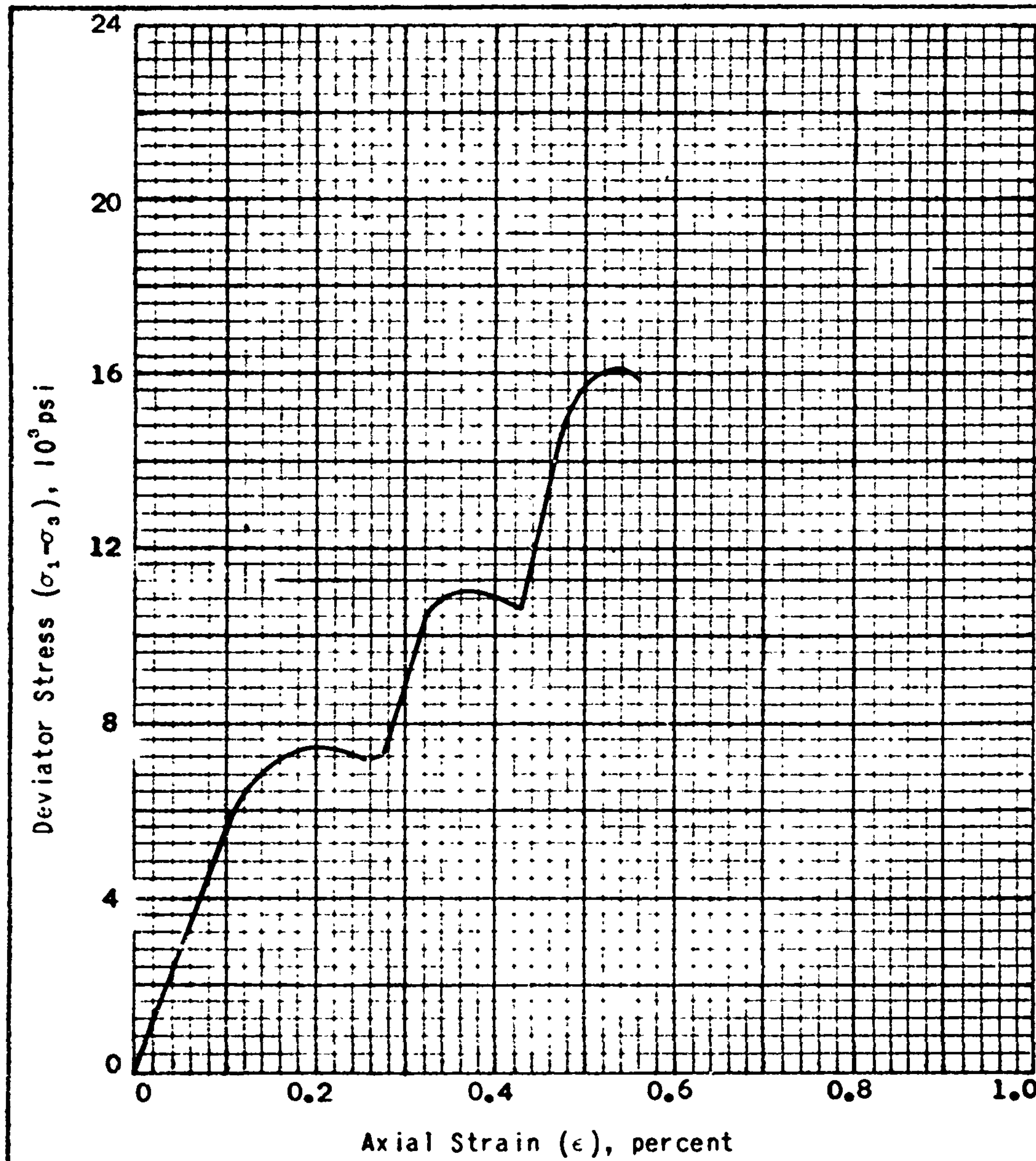
Open Joint Plane



Failure Plane

MRD FORM 1 APR 64 738

FIGURE 52



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 107, MRD Lab. No. 64/90
Core Depth 442.6-444.0 feet
Core Diam. 2.400 in., Core Ht. 4.92 in.
Core Weight, SSD 957.1 gm.

Confining Pressure (σ_3), psi.	Modulus of Elasticity, 10^6 psi,
450	7.41
1,350	8.00
3,000	11.00

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. No large crystals of feldspar were evident in the core specimen. A natural open joint with a rough, very irregular wavy surface dips at about 62 degrees.

In triaxial compression, multi-stage, the core slid on the joint plane. Slight granulation of mineral grains and faint slickensides were observed on the high ridges of the joint plane surfaces.

MRD FORM 1 APR 64 737

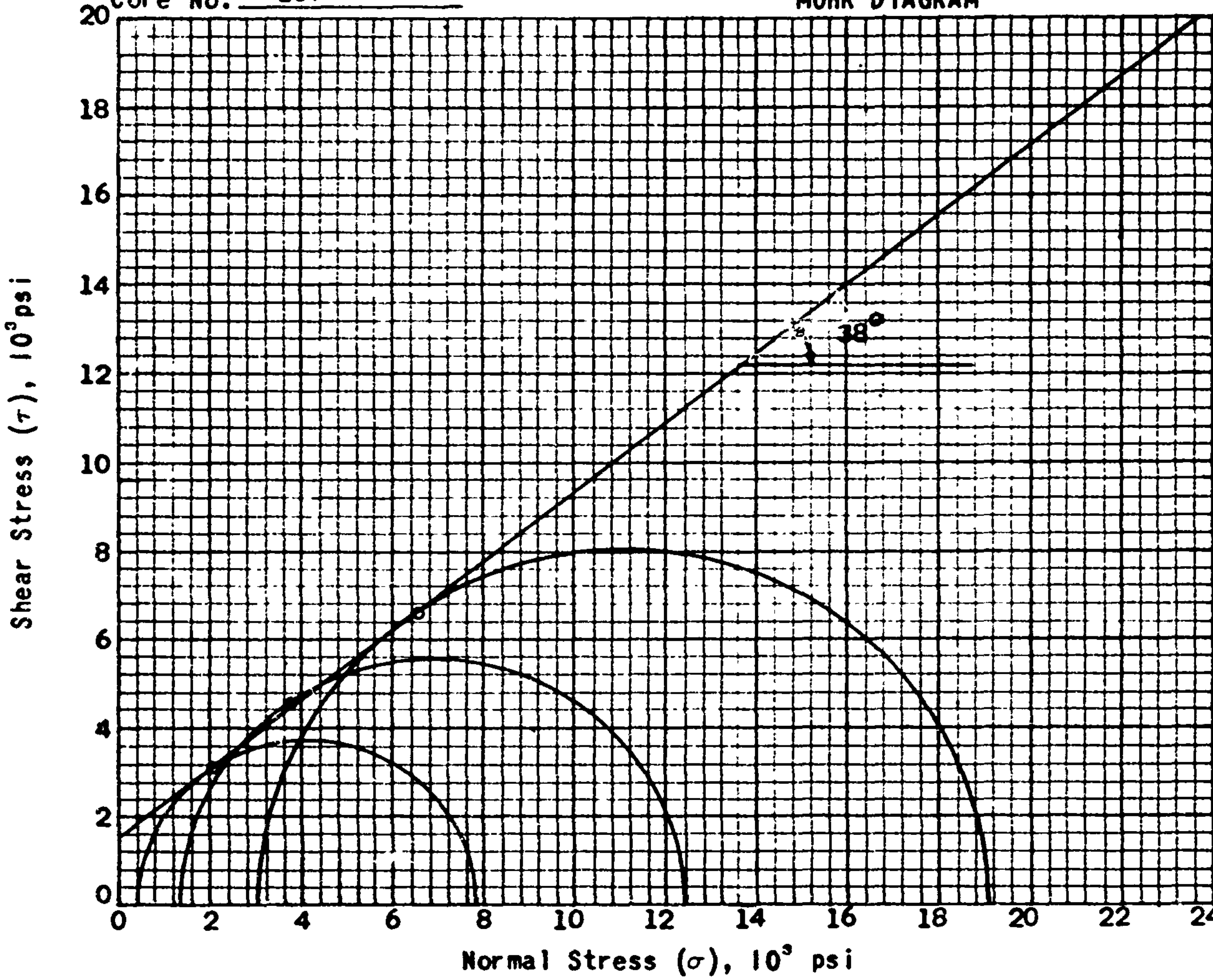
FIGURE 53

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 107

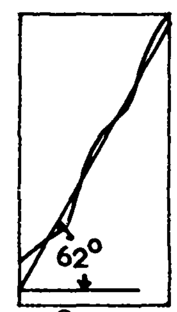
MOHR DIAGRAM



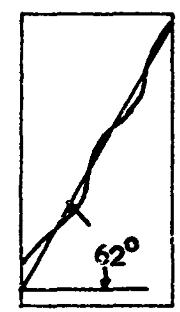
MRD Lab. No. 64/90
PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Open Joint Plane o	Normal Stress (σ), psi Failure Plane o
450	7,830	2,070	2,070
1,350	12,360	3,770	3,770
3,000	19,100	6,540	6,540

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Open Joint Plane o	Shear Stress (τ), psi Failure Plane o
450	7,830	3,060	3,060
1,350	12,360	4,560	4,560
3,000	19,100	6,670	6,670



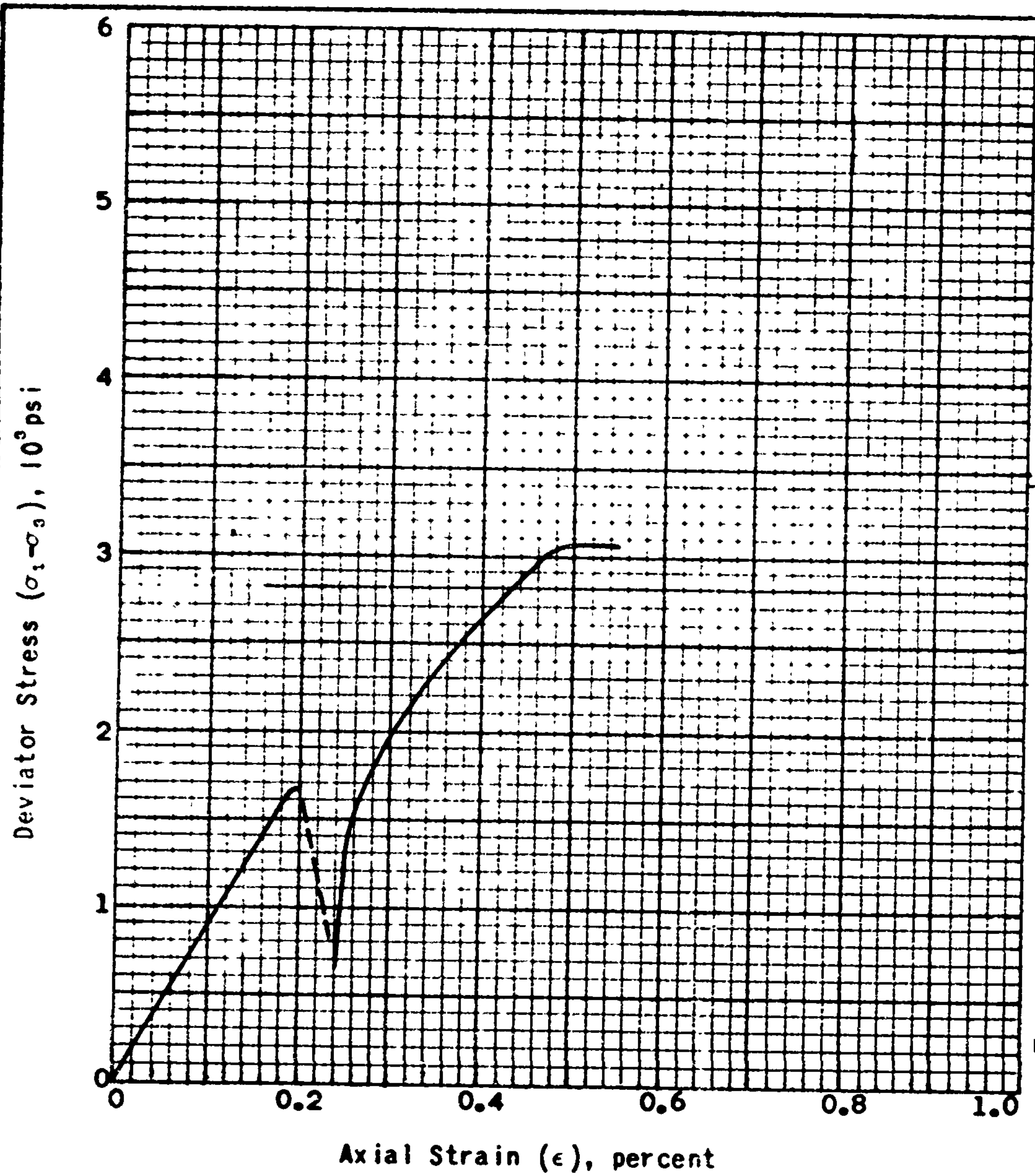
Open Joint Plane



Failure Plane

MRD FORM 1 APR 64 738

FIGURE 54



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 164, MRD Lab. No. 64/90
Core Depth 392.7-393.5 feet
Core Diam. 2.400 in., Core Ht. 4.84 in.
Core Weight, SSD, 945.7 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi,
1	450	0.82
2	1,350	2.86
3		
4		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. No large feldspar crystals are present in the core specimen. A natural open joint with a rough, wavy surface dips at about 66 degrees.

In triaxial compression, multi-stage, the core slid on the joint plane. Slight granulation of mineral grains and faint slickensides were observed on the joint plane surfaces.

MRD FORM
1 APR 64 737

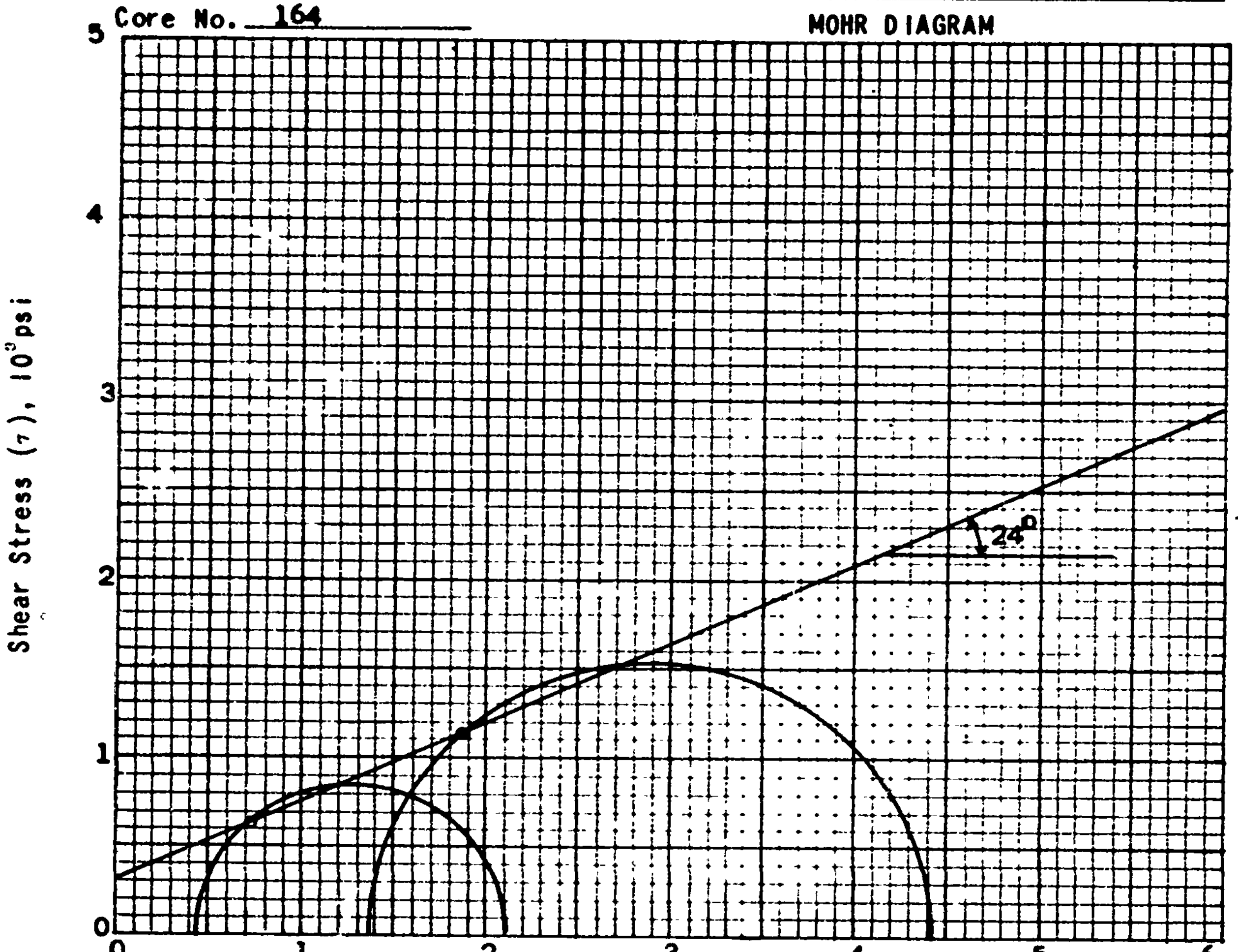
FIGURE 55

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 164

MOHR DIAGRAM

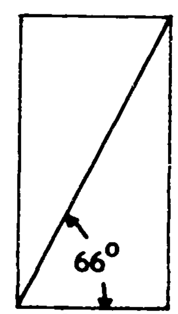


MRD Lab. No. 64/90

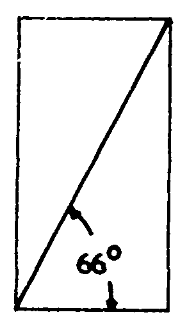
PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Open Joint Plane	Normal Stress (σ), psi Failure Plane
450	2,110	726	726
1,350	4,430	1,861	1,861

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Open Joint Plane	Shear Stress (τ), psi Failure Plane
450	2,110	618	618
1,350	4,430	1,146	1,146



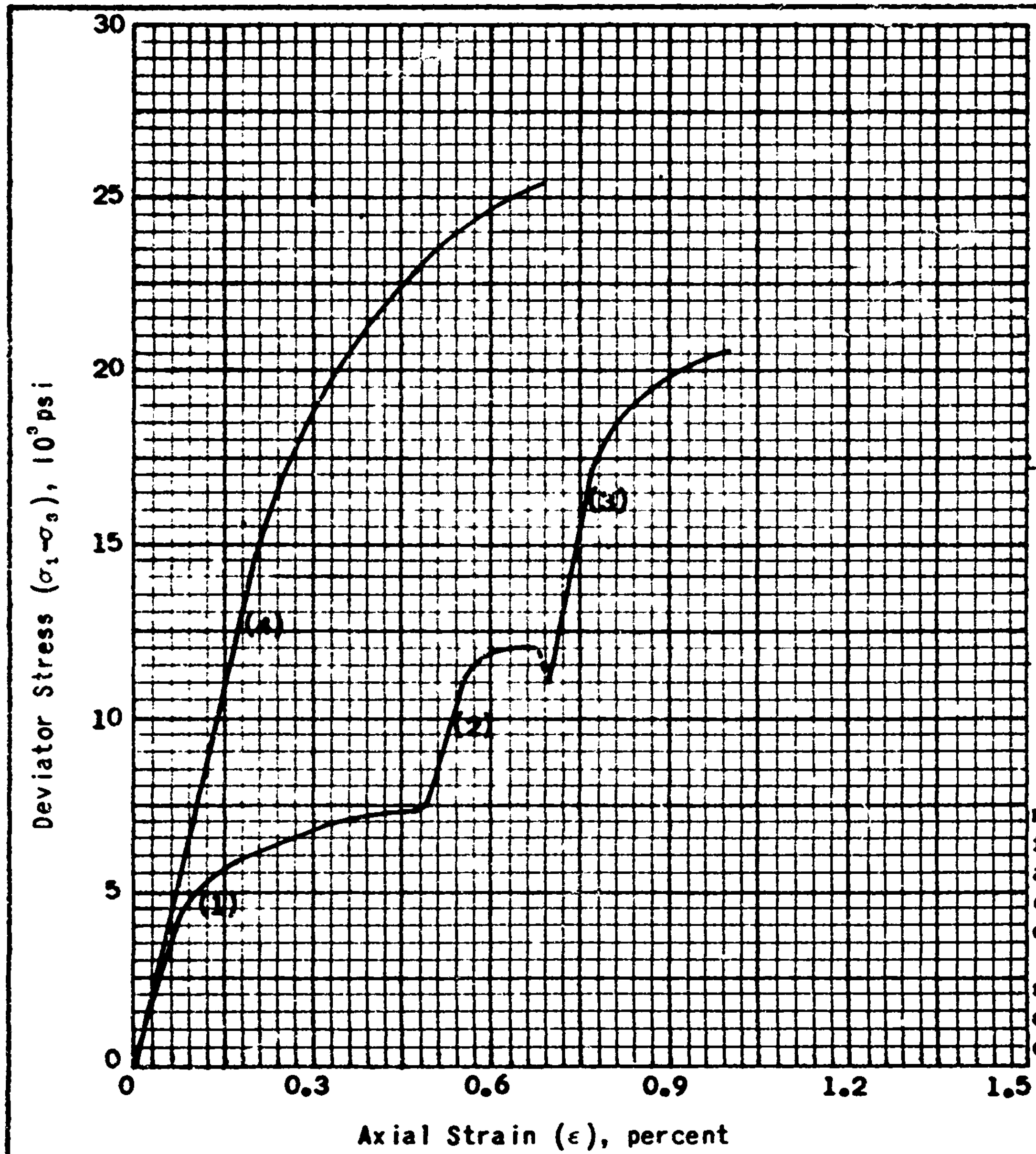
Open Joint Plane



Failure Plane

MRD FORM 1 APR 64 738

FIGURE 56



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 112, MRD Lab. No. 64/90
Core Depth 135.7-136.6 feet
Core Diam. 2.413 in., Core Ht. 4.84 in.
Core Weight, SSD , 968.2 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi,
(1)	1,350	5.21
(2)	3,000	5.21
(3)	6,000	8.67
(4)	10,000	7.77

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:
Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. No large crystals of feldspar were evident. The core specimen contained an open joint lined with quartz, feldspar, and calcite with a small amount of chlorite. This joint dipped at about 50 degrees from the horizontal.
In triaxial compression, multi-stage, the core slid along the joint plane with much granulation of the joint lining material. Slickensides developed on the joint plane surfaces.

MRD FORM 737
1 APR 64

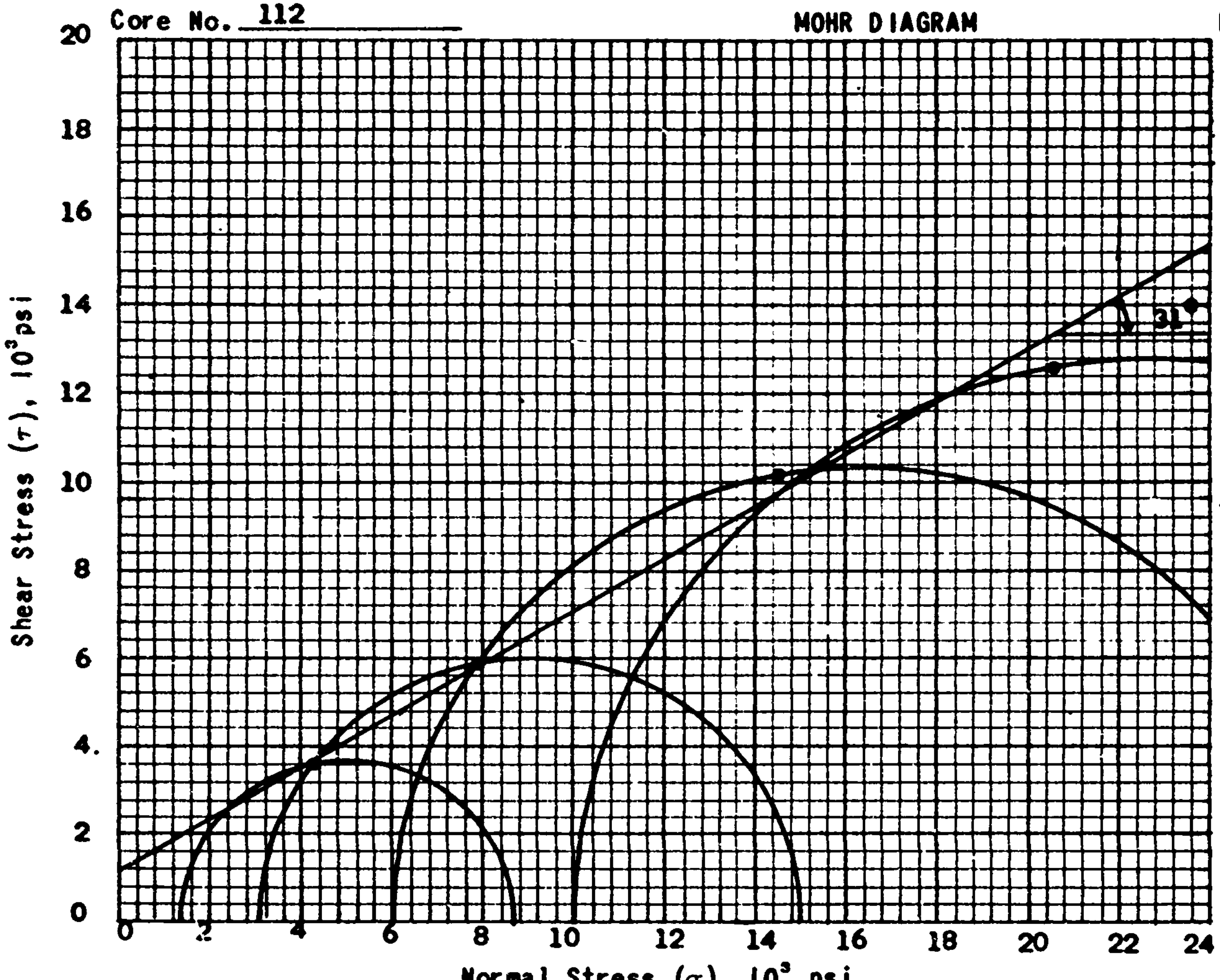
FIGURE 57

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 112

MOHR DIAGRAM

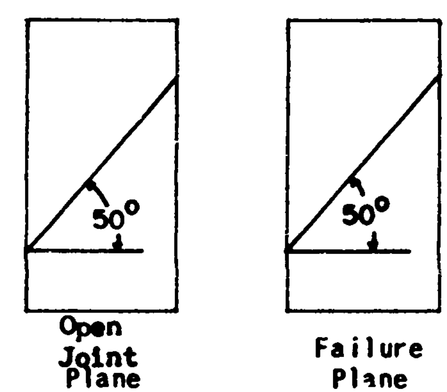


MRD Lab. No. 64/90

PILEDRIVER

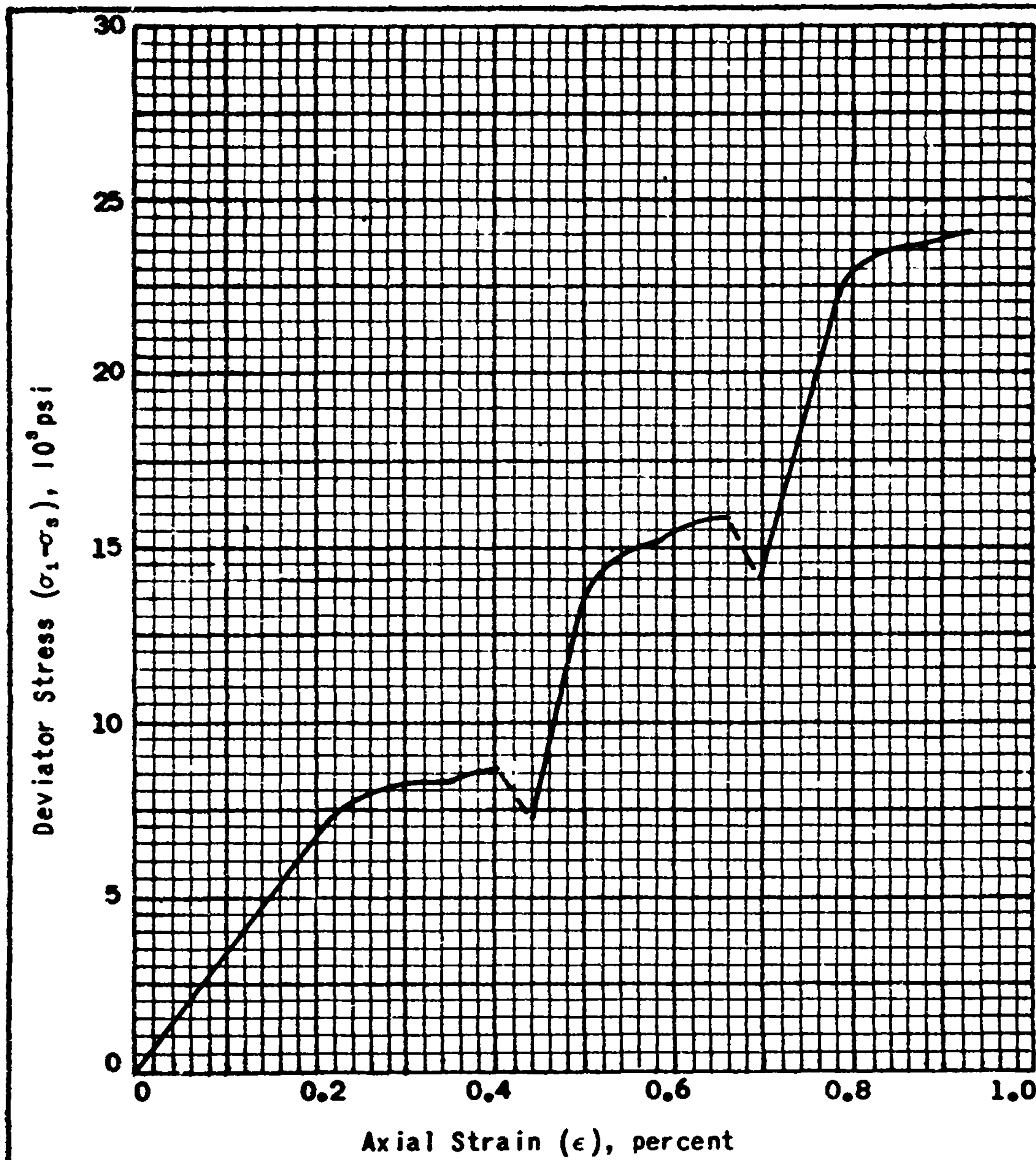
Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi: Open Joint Plane ○	Normal Stress (σ), psi: Failure Plane ○
1,350	8,660	4,370	4,370
3,000	15,080	7,990	7,990
6,000	26,570	14,500	14,500
10,000	35,480	20,480	20,480

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi: Open Joint Plane ○	Shear Stress (τ), psi: Failure Plane ○
1,350	8,660	3,600	3,600
3,000	15,080	5,960	5,960
6,000	26,570	10,140	10,140
10,000	35,480	12,510	12,510



MRD FORM 1 APR 64 738

FIGURE 58



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 159, MRD Lab. No. 64/90
Core Depth 324.0-325.0 feet
Core Diam. 2.402 in., Core Ht. 4.85 in.
Core Weight, SSD, 963.8 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi,
①	3,000	3.34
②	6,000	10.00
③	10,000	8.93
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with fine-to medium-grained groundmass. No large feldspar crystals were present in the core specimen.

In triaxial compression, multi-stage, the core slid on the previously broken joint plane which dipped at 64 degrees. A considerable amount of granulation of mineral grains and well developed slickensides were noted along the joint plane surfaces.

MRD FORM 1 APR 64 737

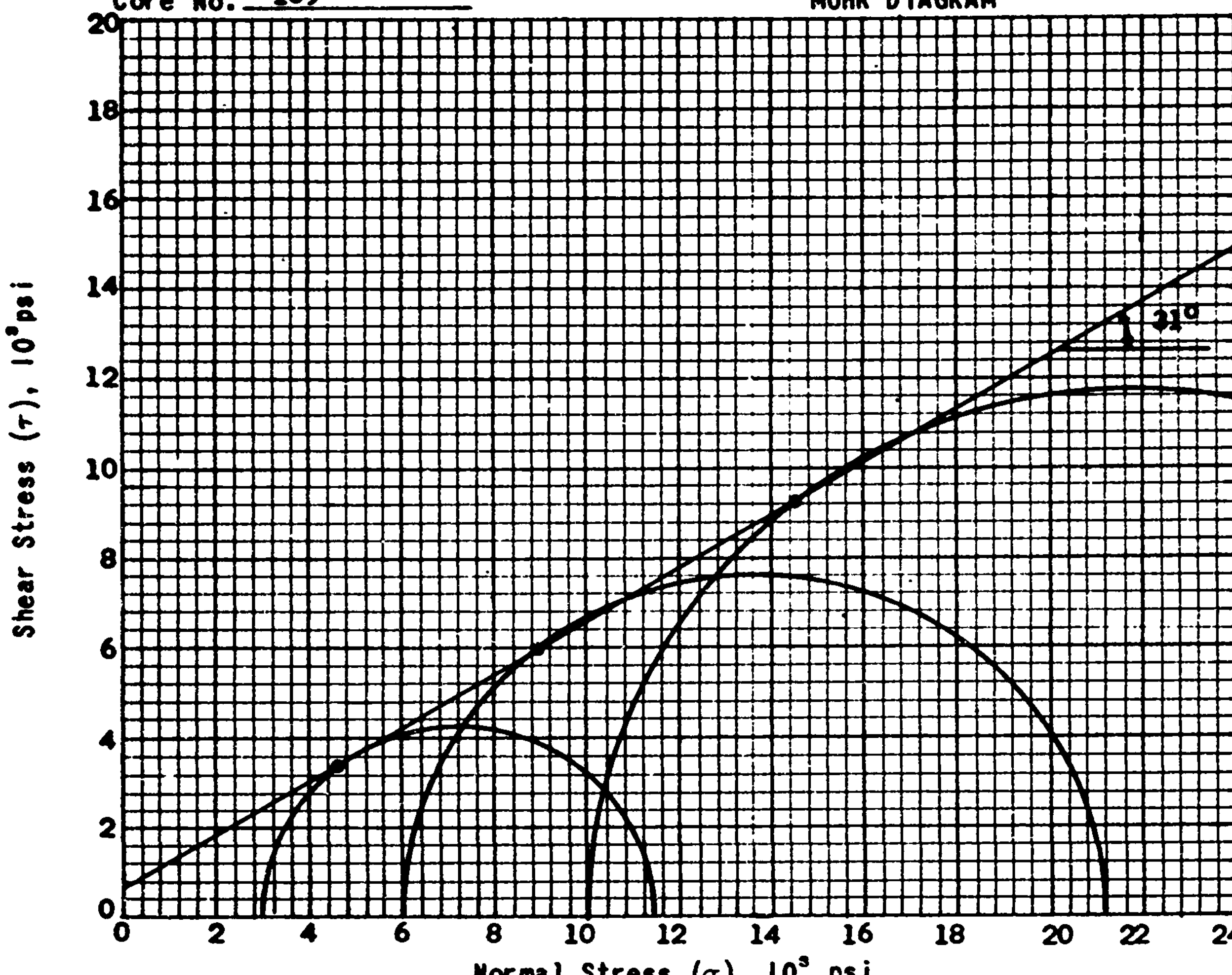
FIGURE 59

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 159

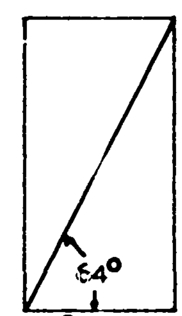
MOHR DIAGRAM



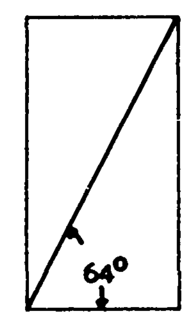
MRD Lab. No. 64/90
PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi: Open Joint Plane ○	Normal Stress (σ), psi: Failure Plane ○
3,000	11,430	4,620	4,620
6,000	21,230	8,920	8,920
10,000	33,510	14,510	14,510

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi: Open Joint Plane ○	Shear Stress (τ), psi: Failure Plane ○
3,000	11,430	3,320	3,320
6,000	21,230	6,000	6,000
10,000	33,510	9,260	9,260



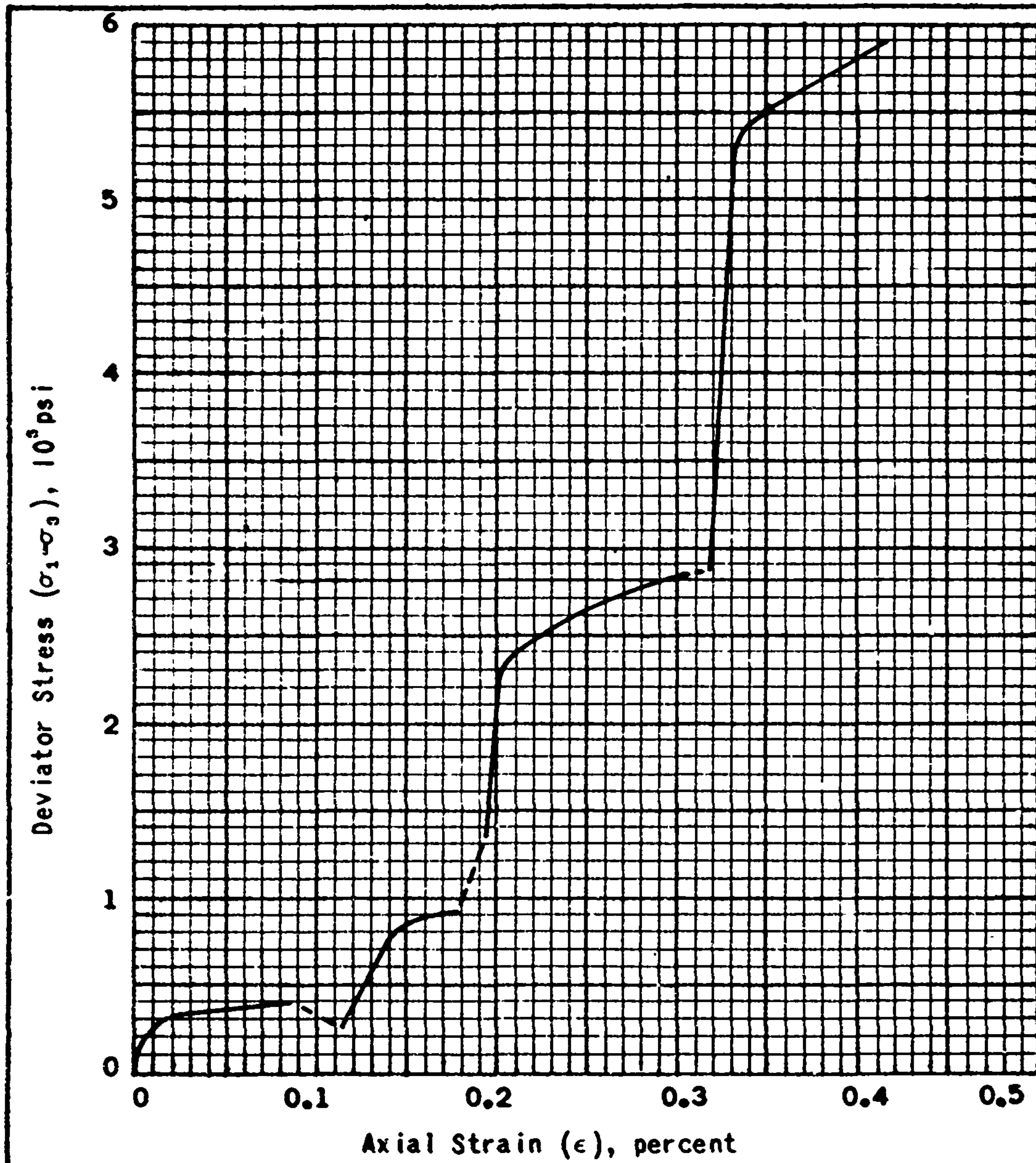
Open Joint Plane



Failure Plane

MRD FORM 1 APR 64 738

FIGURE 60



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 23, MRD Lab. No. 64/90
Core Depth 176.4-177.4 feet
Core Diam. 2.420 in., Core Ht. 4.82 in.
Core Weight, SSD, 970.6 gm.

	Confining Pressure (σ_3), psi.	Modulus of Elasticity, 10^6 psi,
①	150	3.11
②	450	2.08
③	1,350	15.83
④	3,000	19.00

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. Several large feldspar crystals of 3/4-in. length occur in the central portion of the core specimen.

In triaxial compression, multi-stage, the core slid on the sawed joint which dipped at 55 degrees. Slight granulation of mineral grains and faint slickensides were noted along the joint plane surfaces.

MRD FORM
1 APR 64 737

FIGURE 61

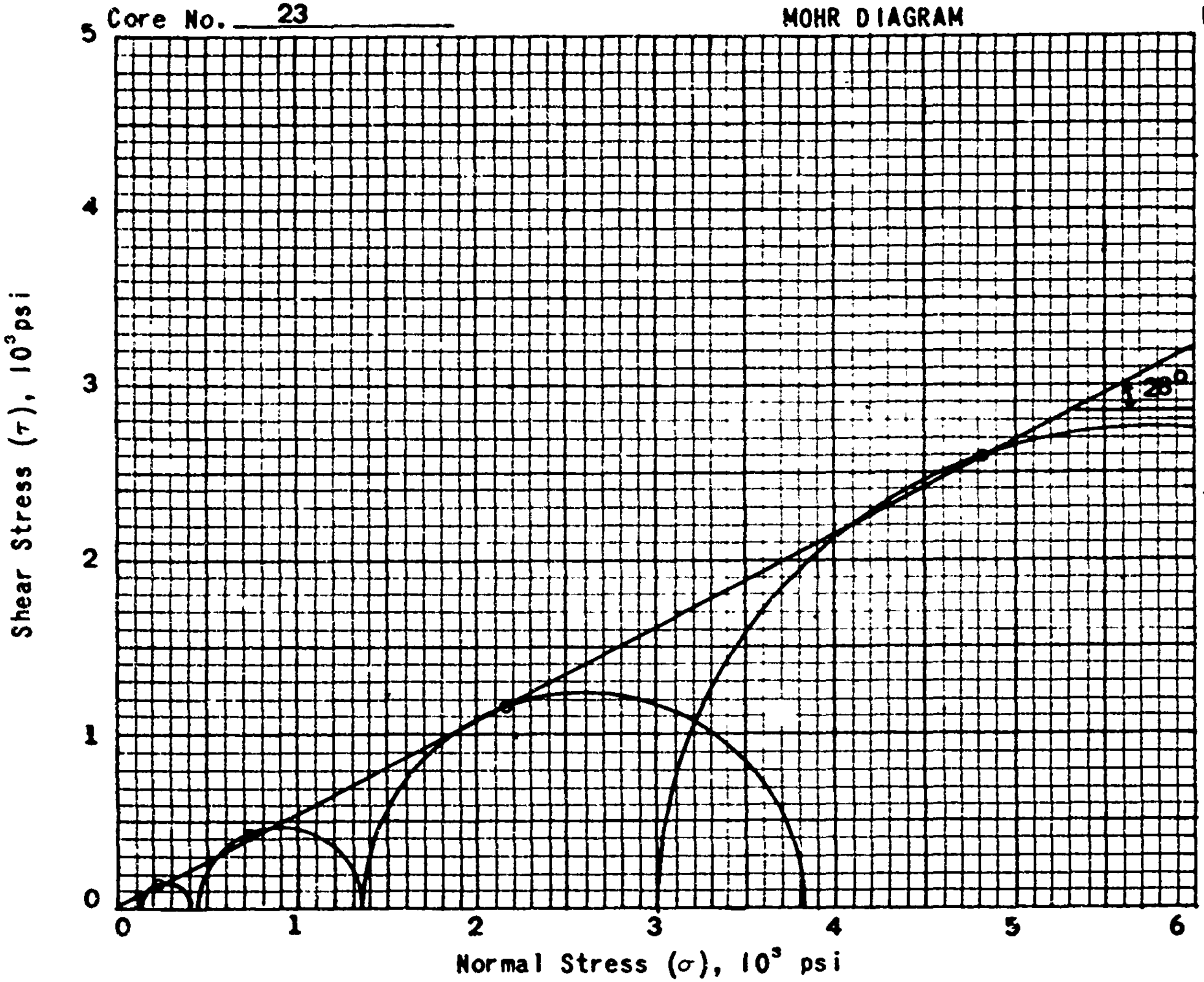
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 23 MRD Lab. No. 64/90

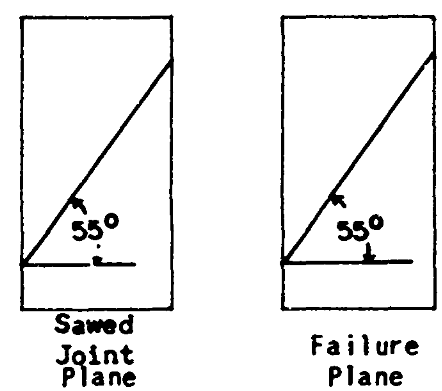
PILEDRIVER

MOHR DIAGRAM



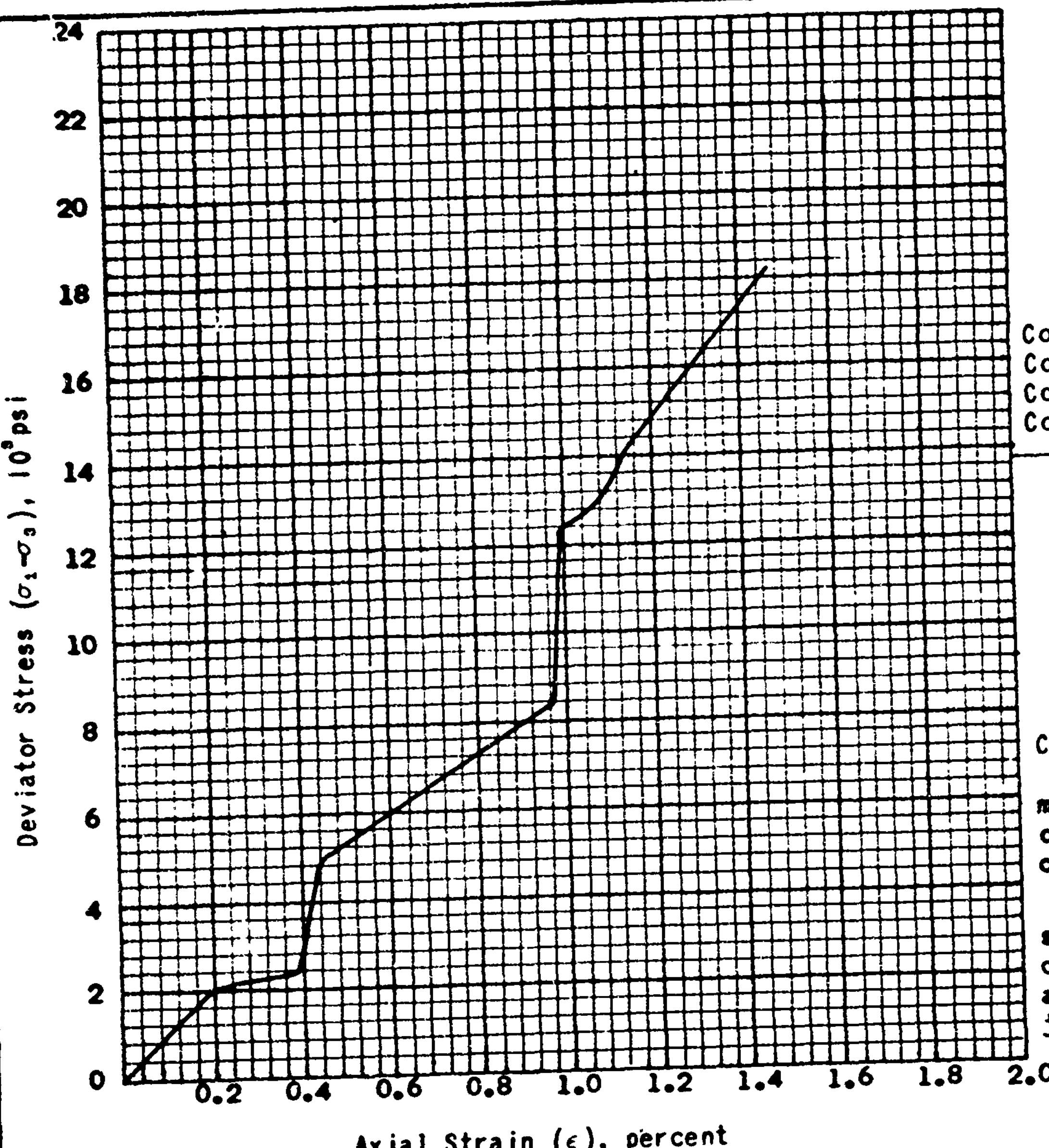
Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Sawed Joint Plane ○	Normal Stress (σ), psi Failure Plane ○
150	430	242	242
450	1,340	743	743
1,350	3,830	2,166	2,166
3,000	8,520	4,815	4,815

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Sawed Joint Plane ○	Shear Stress (τ), psi Failure Plane ○
150	430	132	132
450	1,340	418	418
1,350	3,830	1,165	1,165
3,000	8,520	2,595	2,595



MRD FORM 1 APR 64 738

FIGURE 62



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 22, MRD Lab. No. 64/90
Core Depth 176.4-177.4 feet
Core Diam. 2.419 in., Core Ht. 4.88 in.
Core Weight, SSD, 985.6 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi,
①	450	1.03
②	1,350	4.72
③	3,000	12.14
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. Several feldspar crystals of ½-in. length occur throughout the core specimen.

In triaxial compression, multi-stage, the core slid on the sawed joint which dipped at 45 degrees. Slight granulation of mineral grains and faint slickensides were observed along the joint plane surfaces.

FIGURE 63

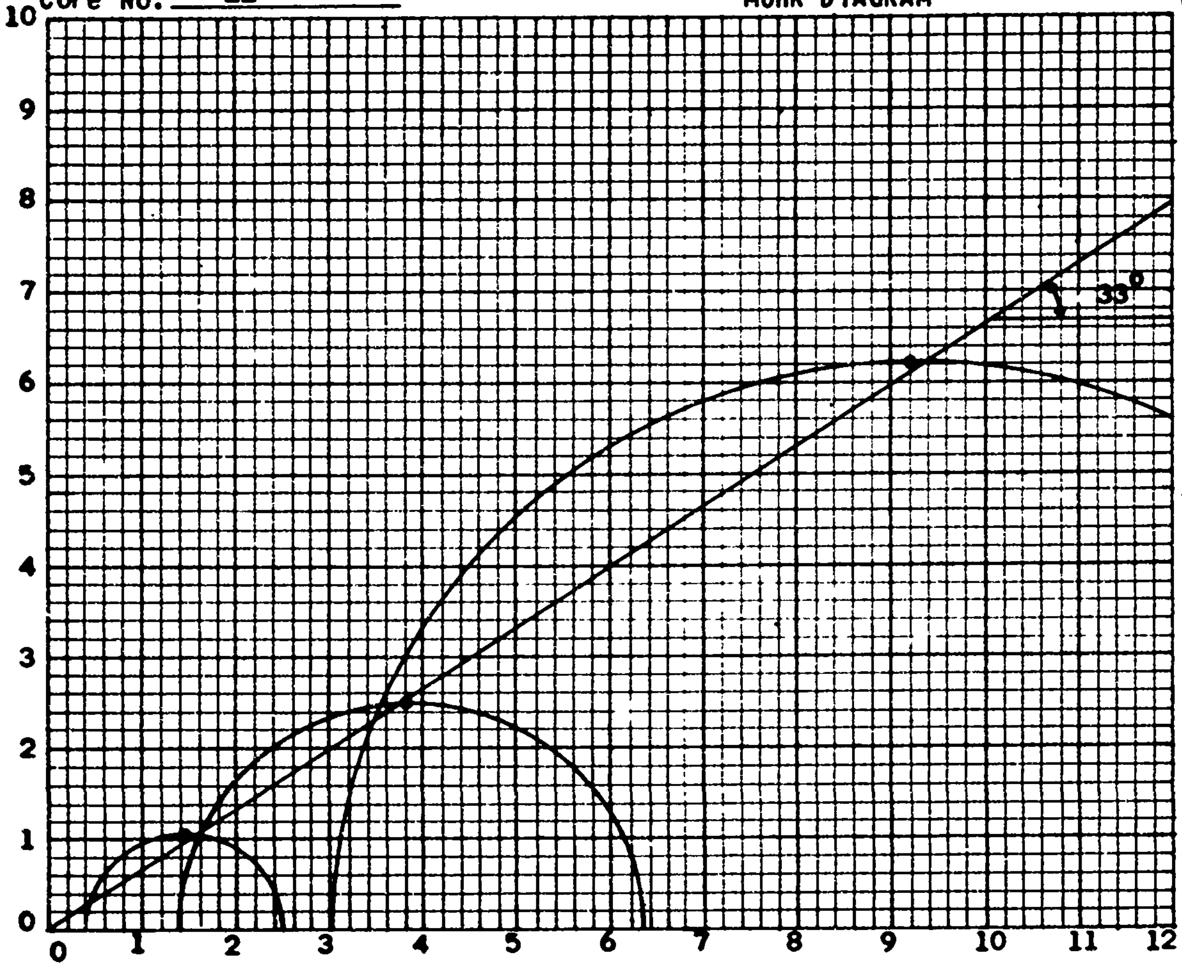
MRD FORM 737
1 APR 64

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 22

MOHR DIAGRAM

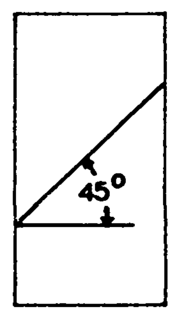


MRD Lab. No. 64/90

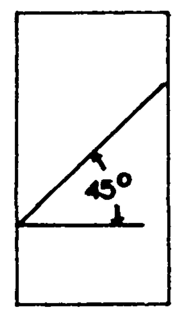
PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi: Sawed Joint Plane ○	Normal Stress (σ), psi: Failure Plane ○
450	2,470	1,460	1,460
1,350	6,290	3,820	3,820
3,000	15,430	9,220	9,220

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi: Sawed Joint Plane ○	Shear Stress (τ), psi: Failure Plane ○
450	2,470	1,010	1,010
1,350	6,290	2,470	2,470
3,000	15,430	6,220	6,220



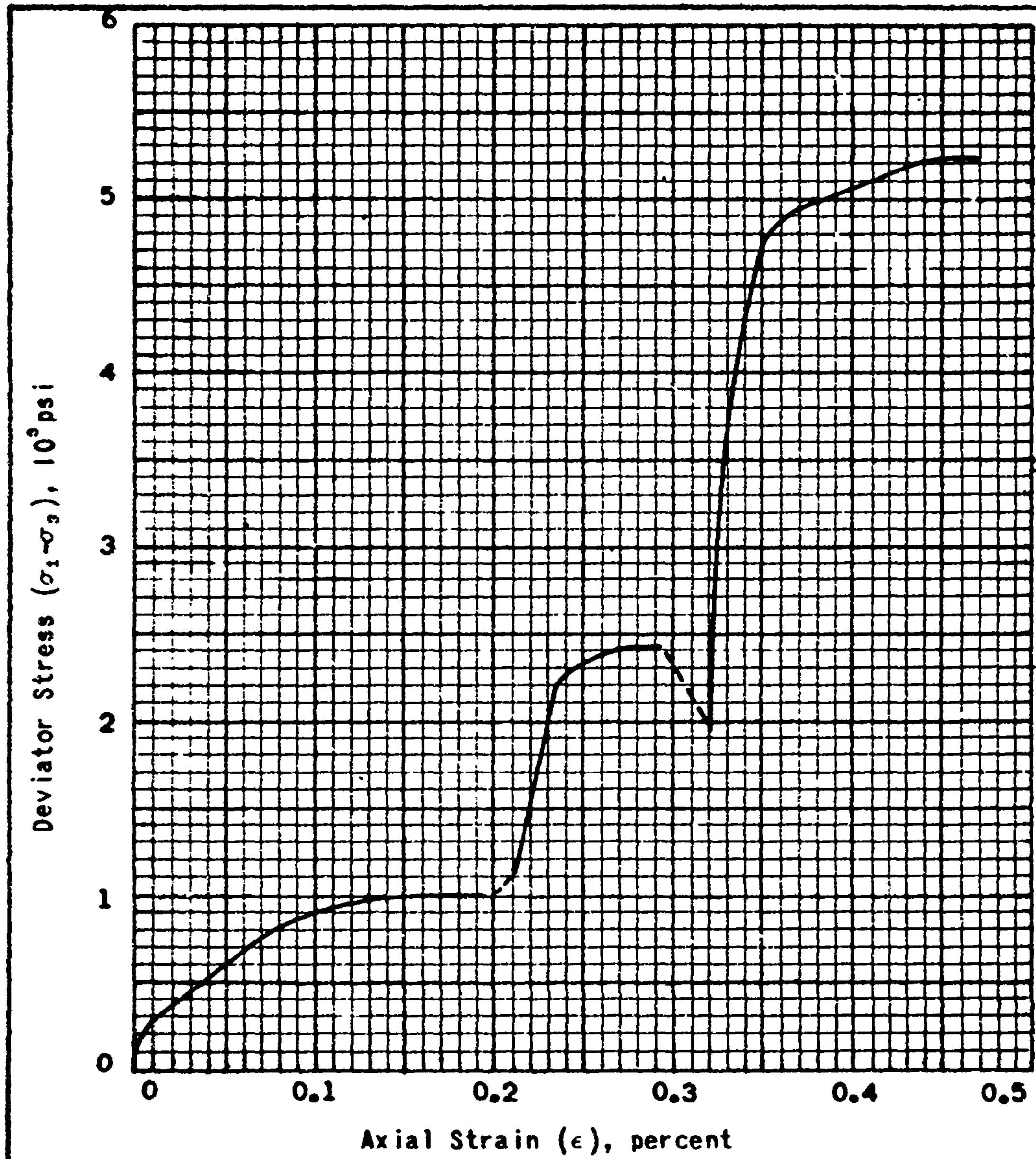
Sawed Joint Plane



Failure Plane

MRD FORM 1 APR 64 738

FIGURE 64



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 11, MRD Lab. No. 64/90
Core Depth 35.6-36.5 feet
Core Diam. 2.408 in., Core Ht. 4.95 in.
Core Weight, SSD, 979.8 gm.

	Confining Pressure (σ_3), psi.	Modulus of Elasticity, 10^6psi.
①	450	0.82
②	1,350	4.66
③	3,000	12.07
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. One large, pink feldspar crystal of 1½-in. length occurs in an end section of the core specimen.

In triaxial compression, multi-stage, the core slid on the sawed joint which dipped at 62 degrees. Slight granulation of mineral grains and faint slickensides were observed along the joint plane surfaces.

MRD FORM
1 APR 64 737

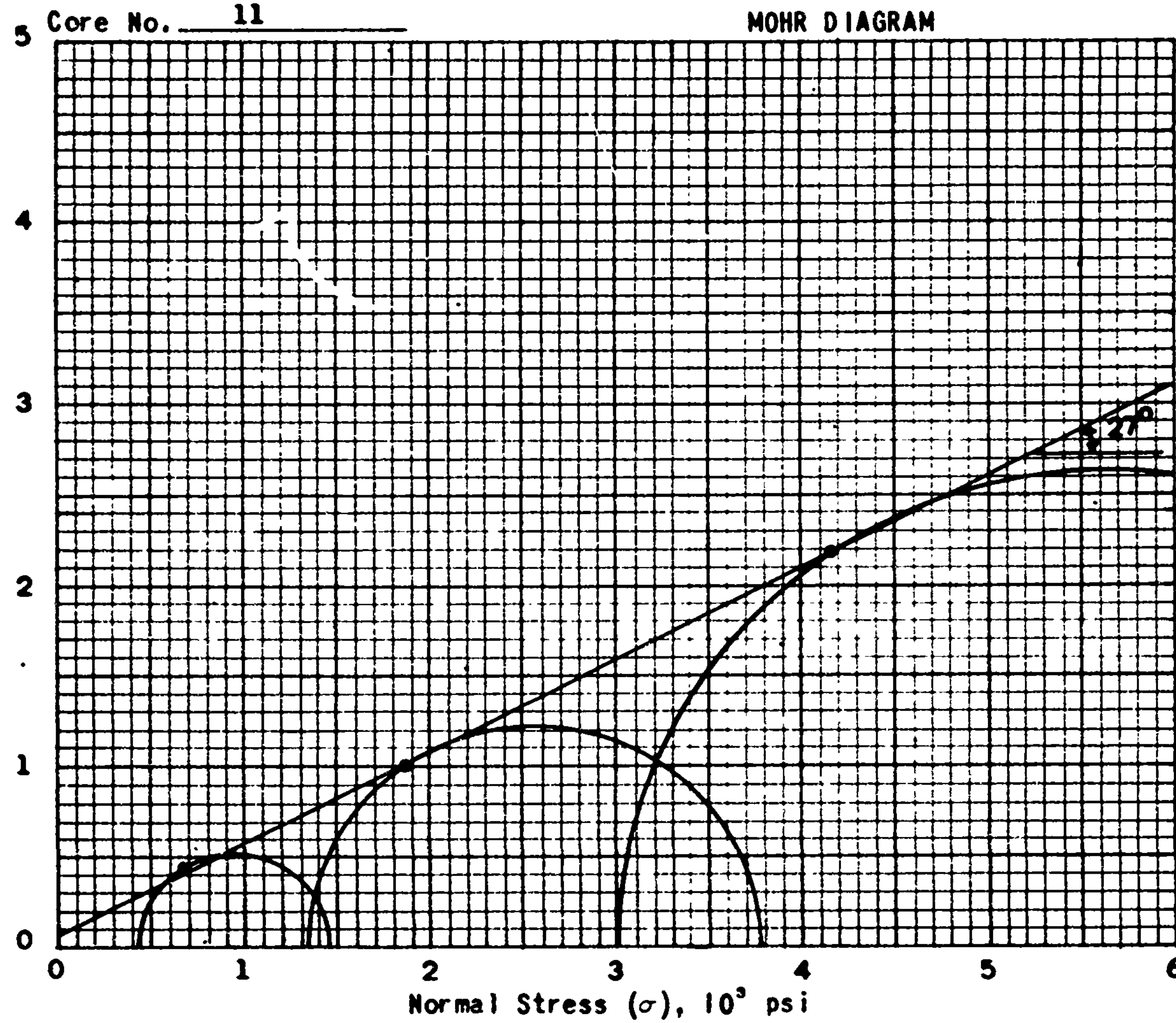
FIGURE 65

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 11

MOHR DIAGRAM

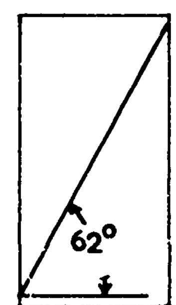


MRD Lab. No. 64/90

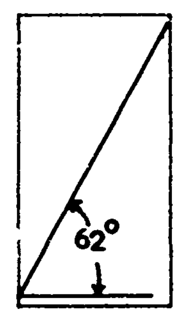
PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi: Sawed Joint Plane o	Normal Stress (σ), psi: Failure Plane o
450	1,460	670	670
1,350	3,770	1,880	1,880
3,000	8,210	4,150	4,150

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi: Sawed Joint Plane o	Shear Stress (τ), psi: Failure Plane o
450	1,460	420	420
/ 6,350	3,770	1,000	1,000
3,000	8,210	2,160	2,160



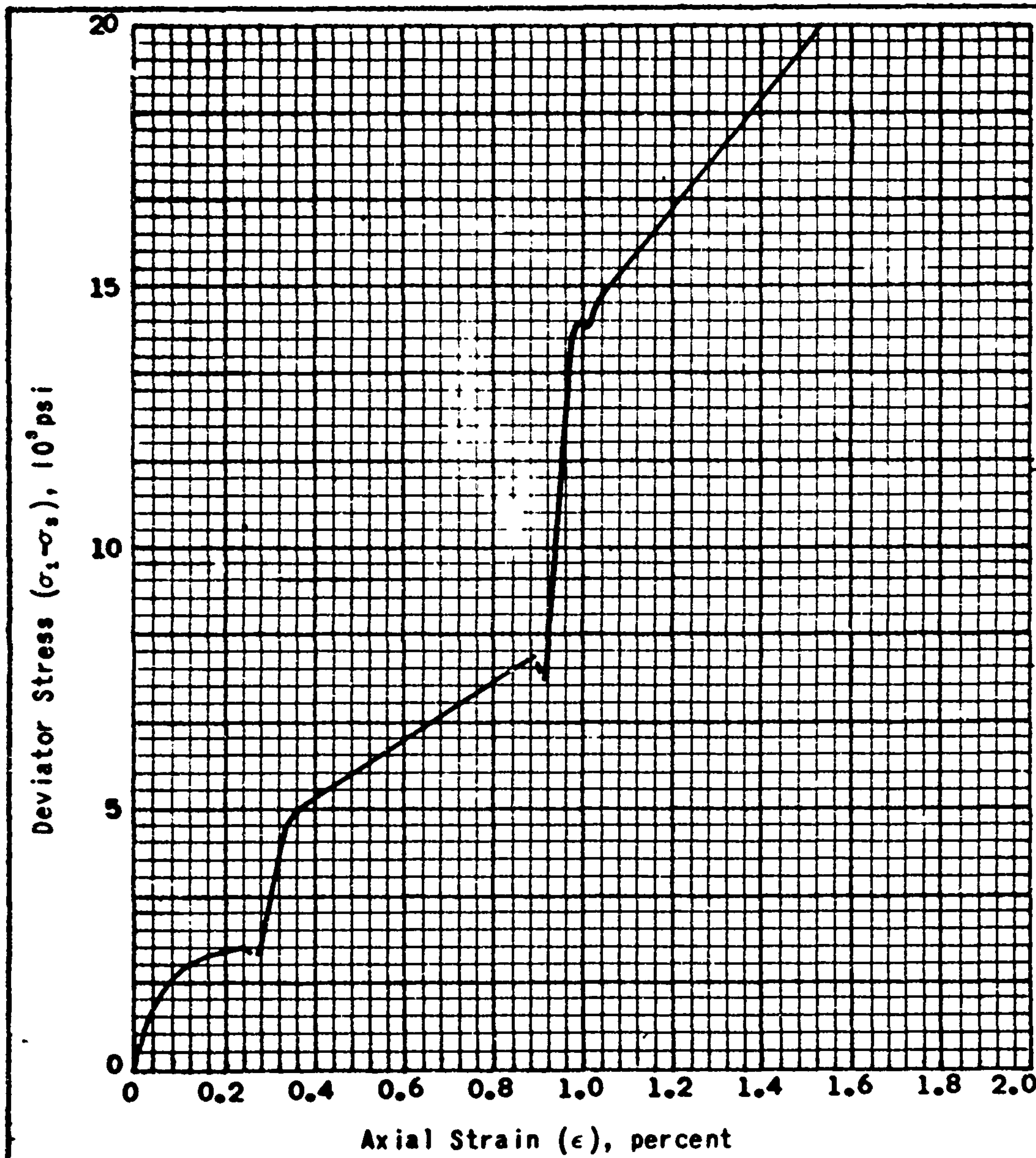
Sawed Joint Plane



Failure Plane

MRD FORM 1 APR 64 738

FIGURE 66



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 12, MRD Lab. No. 64/90
Core Depth 35.6-36.5 feet
Core Diam. 2.406 in., Core Ht. 4.88 in.
Core Weight, SSD, 970.8 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi,
①	1.35	2.61
②	3.00	5.00
③	6.00	11.70
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. One large pink feldspar crystal of 2½-in. length occurs in an end section of the core specimen.

In triaxial compression, multi-stage, the core slid on the sawed joint which dipped at 45 degrees. Slight granulation of mineral grains and faint slickensides were observed along the joint plane surfaces.

MRD FORM
1 APR 64 737

FIGURE 67

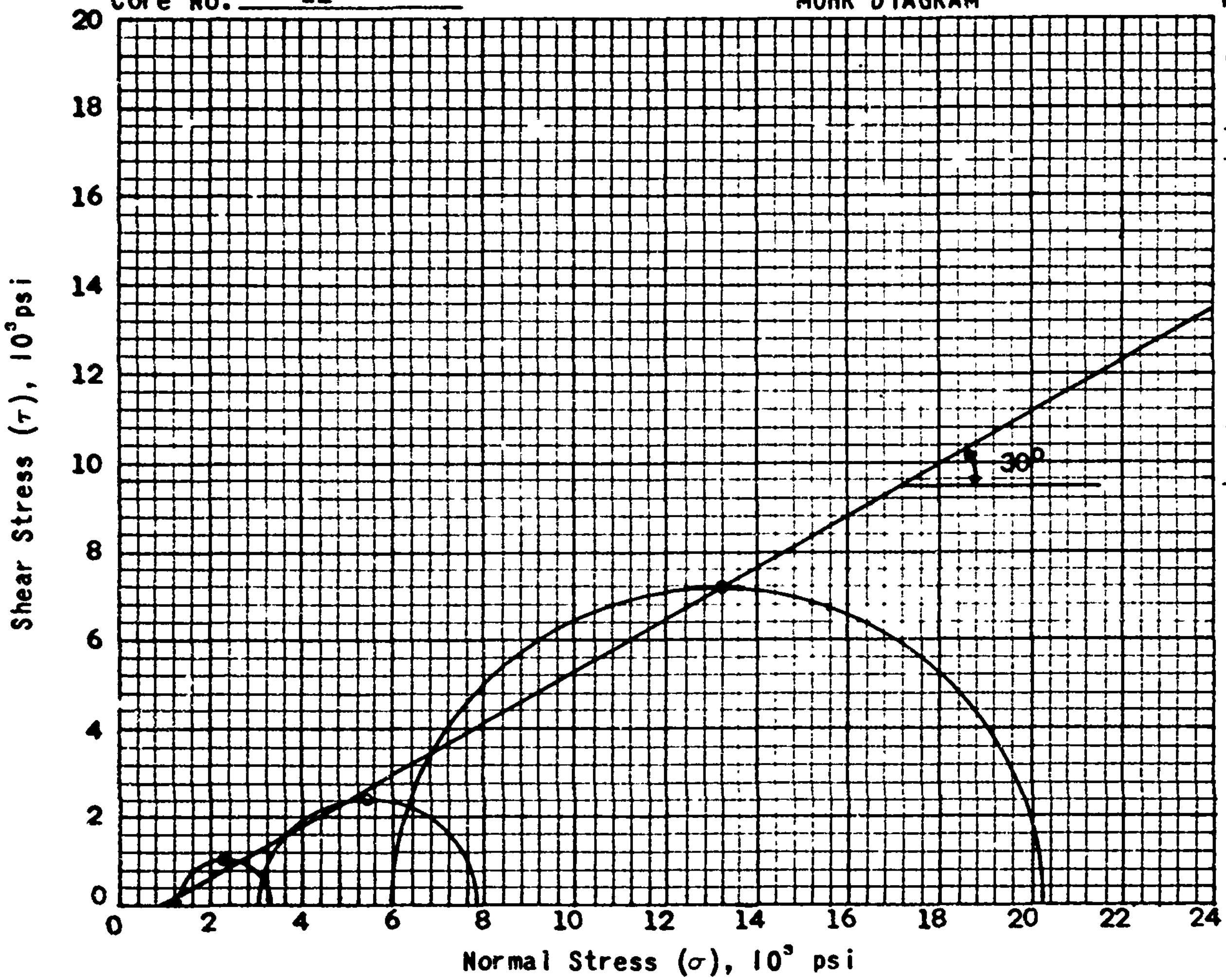
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 12

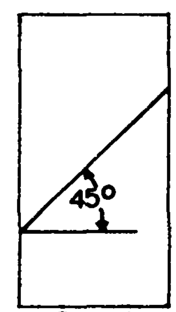
MRD Lab. No. 64/90 PILEDRIVER

MOHR DIAGRAM

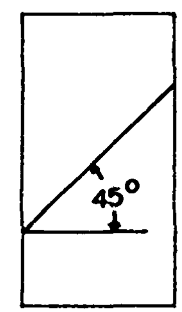


Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Sawed Joint Plane o	Normal Stress (σ), psi Failure Plane o
1,350	3,350	2,350	2,350
3,000	7,800	5,400	5,400
6,000	20,260	13,130	13,130

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Sawed Joint Plane o	Shear Stress (τ), psi Failure Plane o
1,350	3,350	1,000	1,000
3,000	7,800	2,400	2,400
6,000	20,260	7,130	7,130



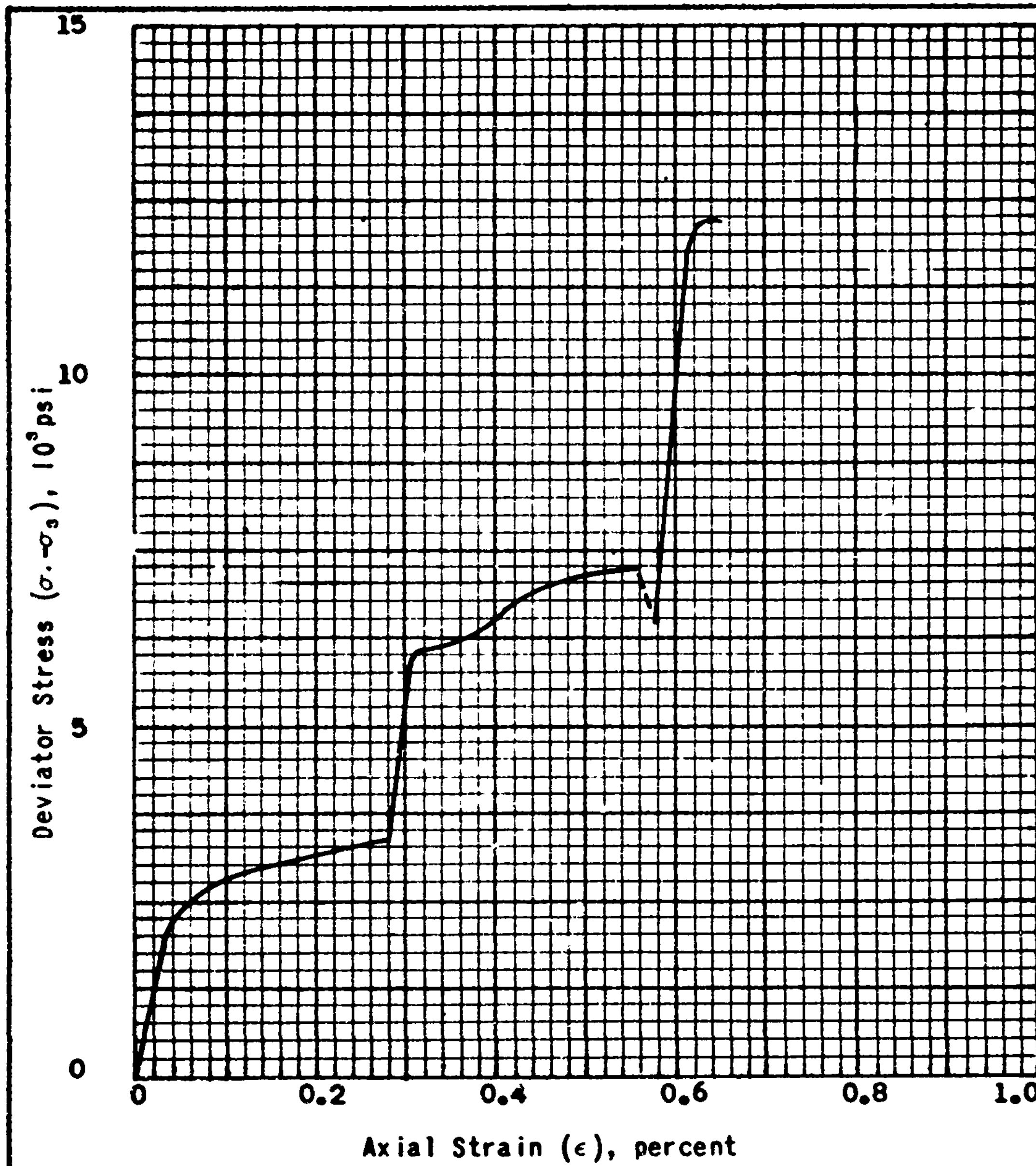
Sawed Joint Plane



Failure Plane

MRD FORM 1 APR 64 738

FIGURE 68



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 18, MRD Lab. No. 64/90
Core Depth 188.8-190.4 feet
Core Diam. 2.409 in., Core Ht. 5.00 in.
Core Weight, SSD, 978.3 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi,
①	1,350	6.32
②	3,000	11.05
③	6,000	13.82
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. One large feldspar crystal of 1-in. length occurs in an end section of the core specimen.

In triaxial compression, multi-stage, the core slid on the sawed joint which dipped at 55 degrees. Slight granulation of mineral grains and faint slickensides were observed along the joint plane surfaces.

MRD FORM 737
1 APR 64

FIGURE 69

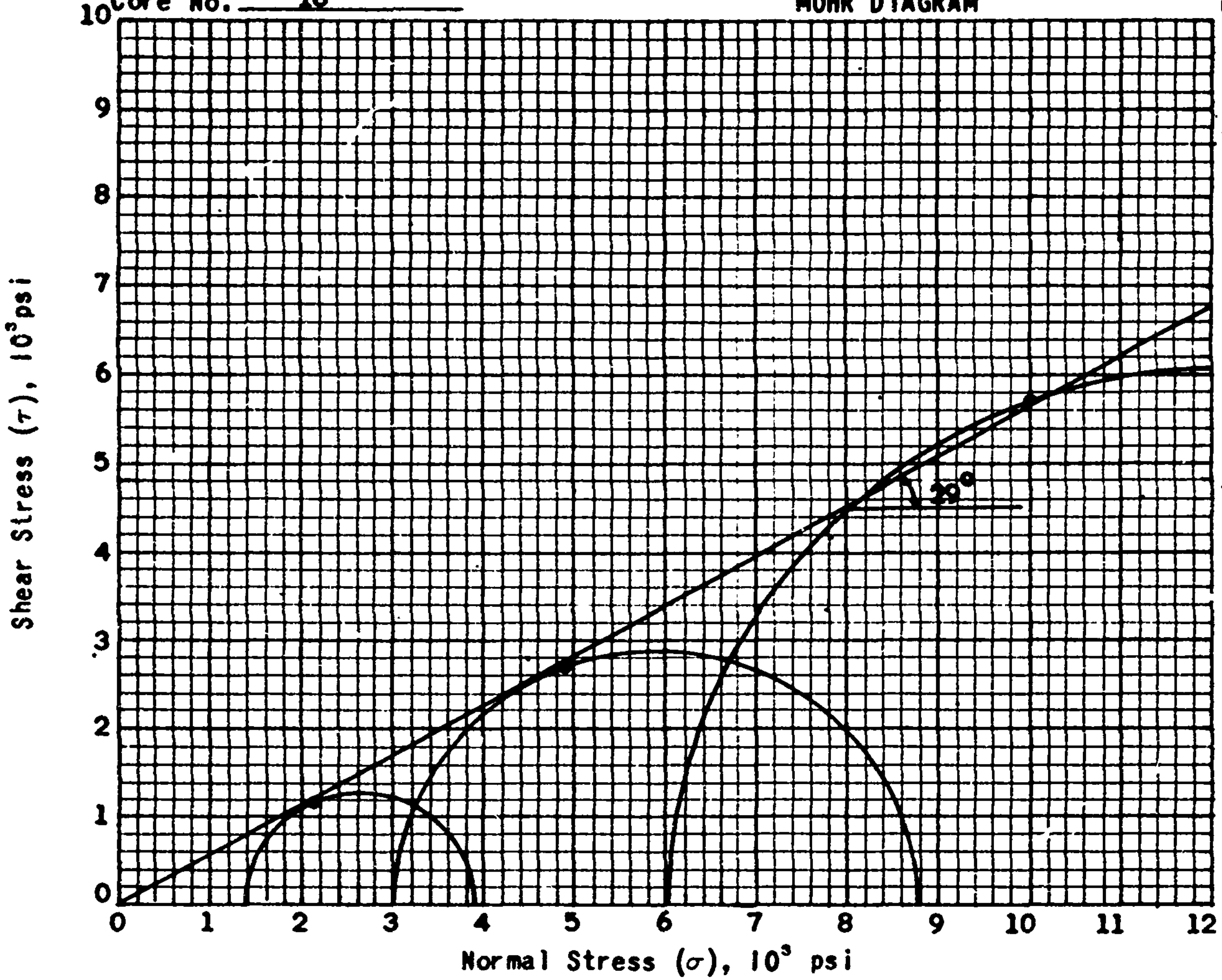
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 18

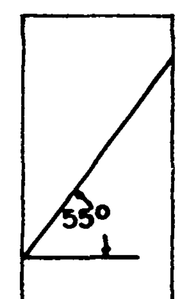
MRD Lab. No. 64/90
PILEDRIVER

MOHR DIAGRAM

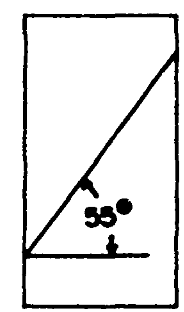


Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Sawed Joint Plane ○	Normal Stress (σ), psi Failure Plane ○
1,350	3,830	2,170	2,170
3,000	8,750	4,890	4,890
6,000	18,170	10,000	10,000

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Sawed Joint Plane ○	Shear Stress (τ), psi Failure Plane ○
1,350	3,830	1,170	1,170
3,000	8,750	2,700	2,700
6,000	18,170	5,720	5,720



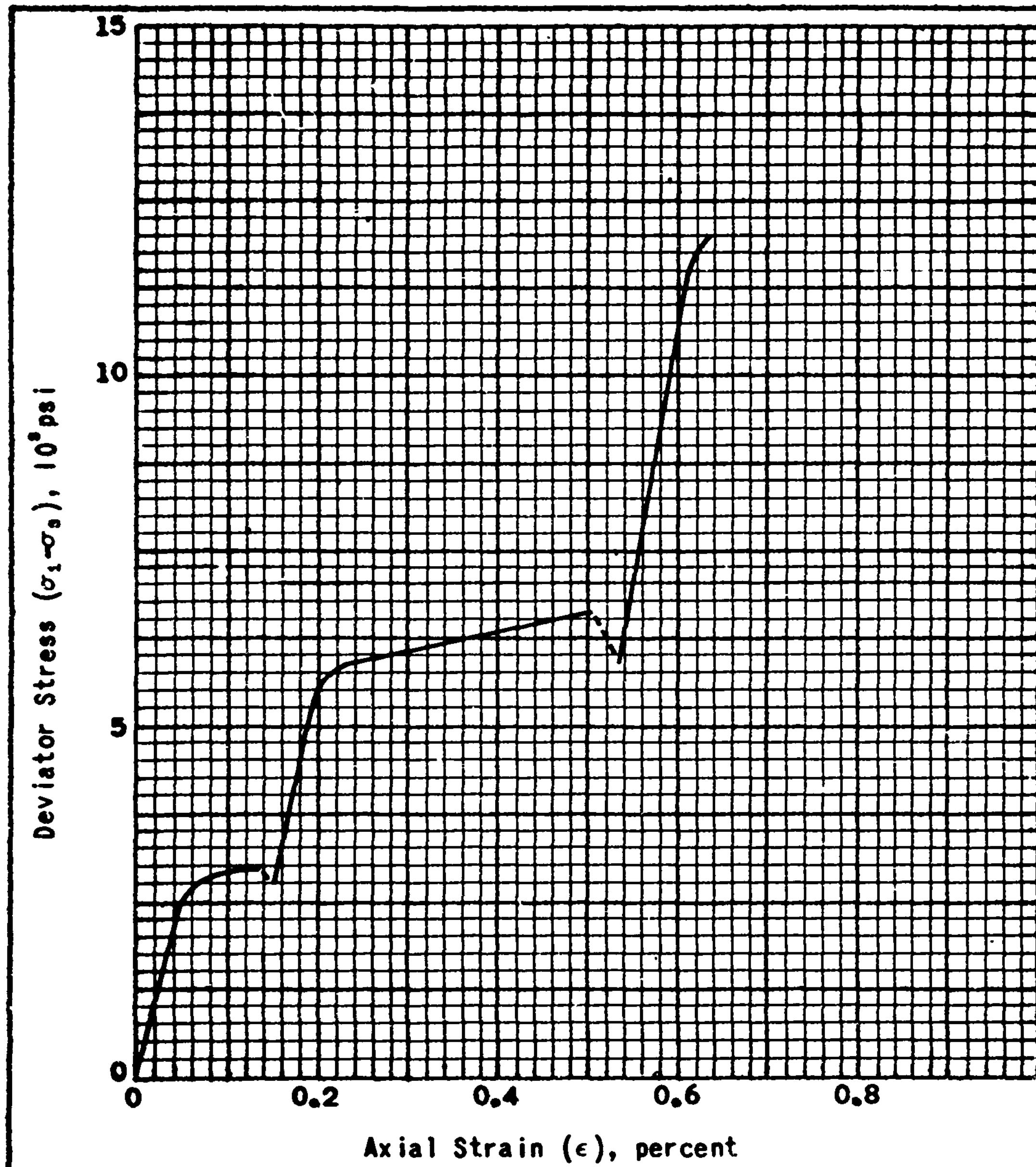
Sawed Joint Plane



Failure Plane

MRD FORM 1 APR 64 738

FIGURE 70



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 27, MRD Lab. No. 64/90
Core Depth 509.7-510.6 feet
Core Diam. 2.389 in., Core Ht. 4.95 in.
Core Weight, SSD, 959.4 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6 psi,
①	1,350	4.09
②	3,000	6.56
③	6,000	7.60
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. A single feldspar crystal of ½-in. length occurs near each end of the core specimen.

In triaxial compression, multi-stage, the core slid on the sawed joint which dipped at 62 degrees. Slight granulation of mineral grains and faint slickensides were observed along the joint plane surfaces.

MRD FORM
1 APR 64 737

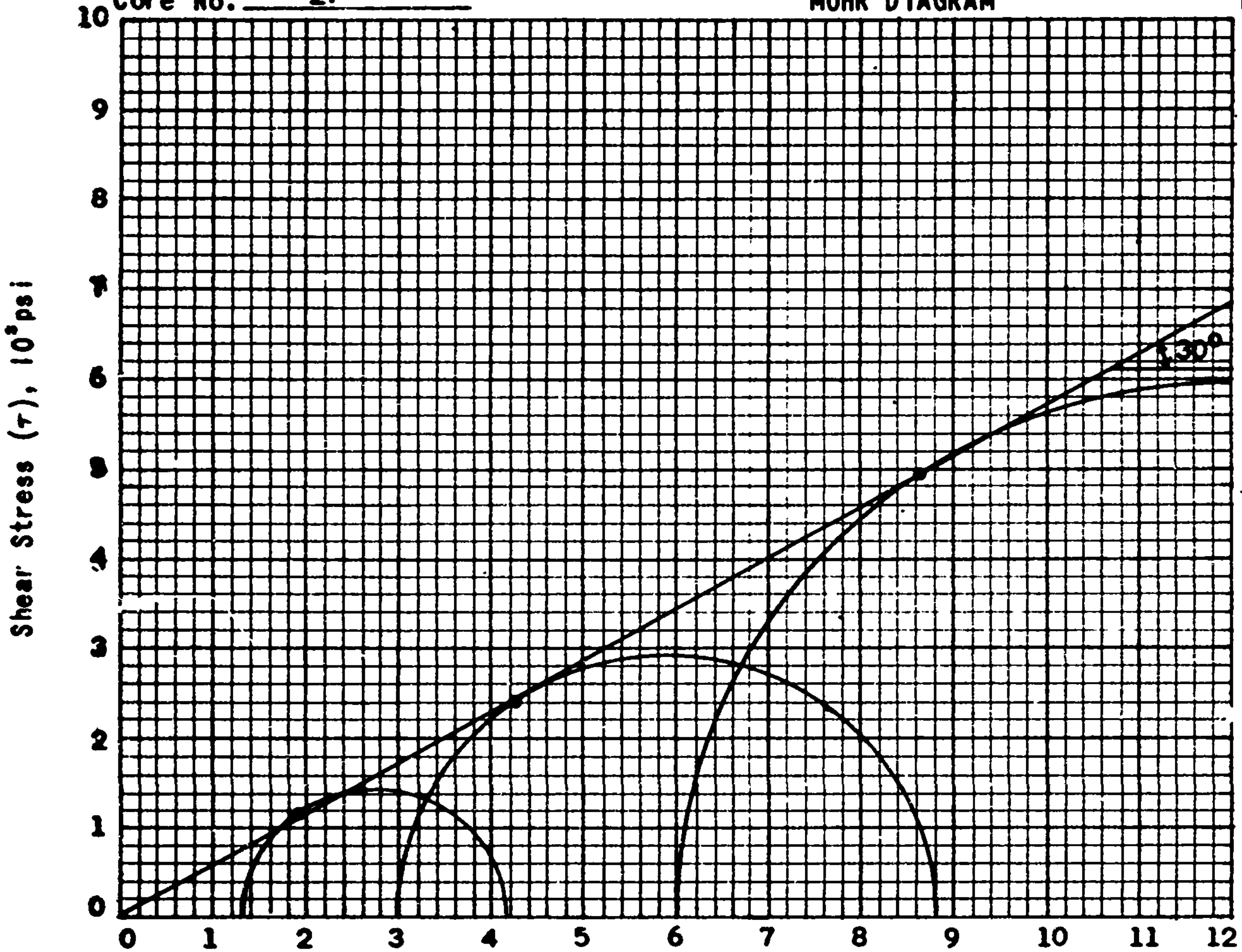
FIGURE 71

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 27

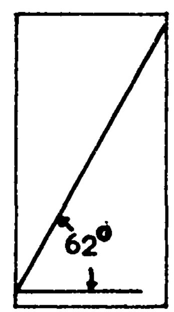
MOHR DIAGRAM



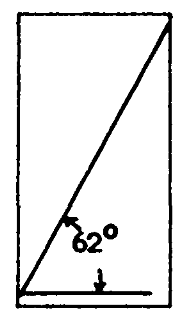
MRD Lab. No. 64/90
PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi: Sawed Joint Plane ○	Normal Stress (σ), psi: Failure Plane ○
1,350	4,140	1,960	1,960
3,000	8,810	4,280	4,280
6,000	17,940	8,630	8,630

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi: Sawed Joint Plane ○	Shear Stress (τ), psi: Failure Plane ○
1,350	4,140	1,160	1,160
3,000	8,810	2,400	2,400
6,000	17,940	4,940	4,940



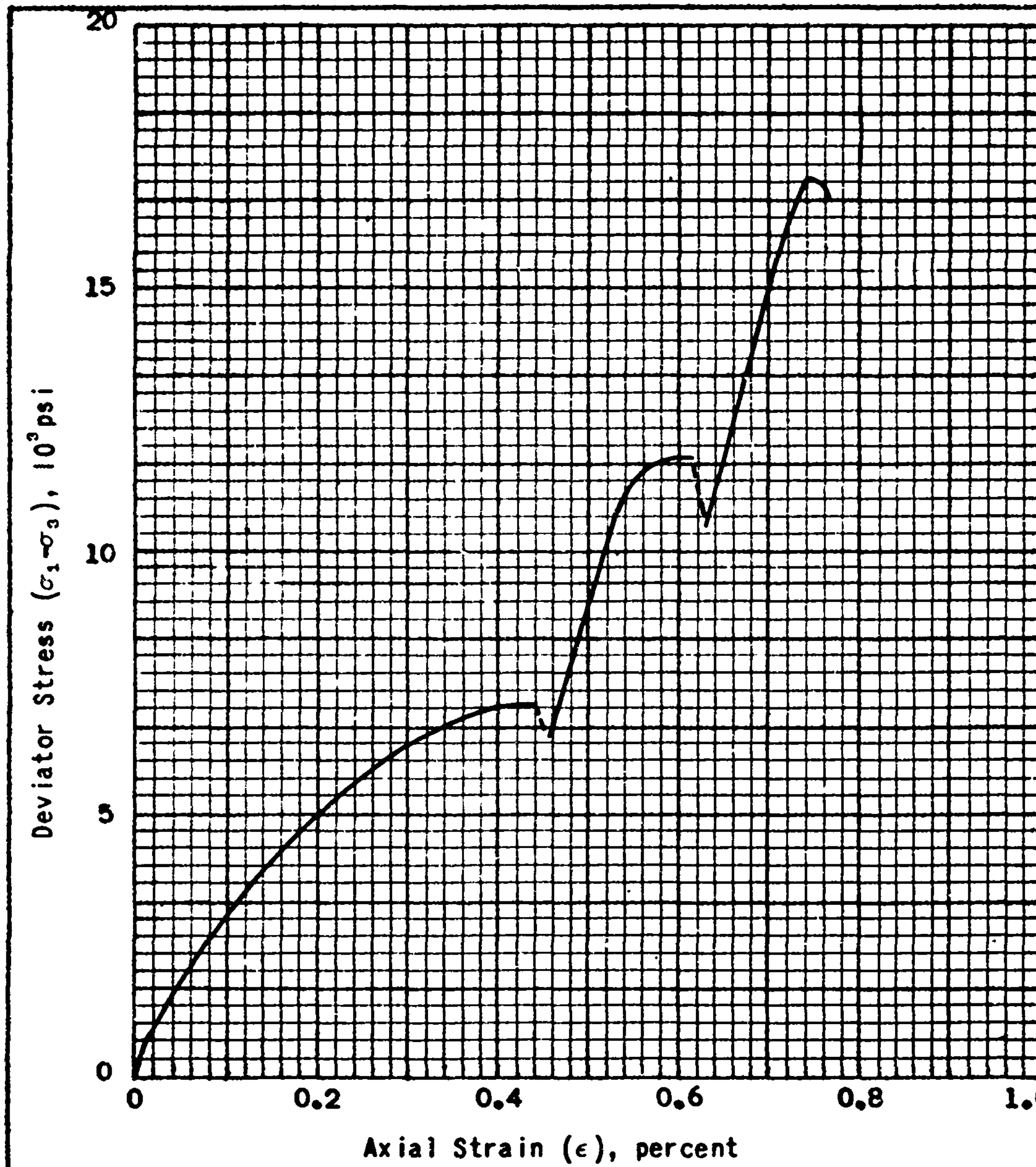
Sawed Joint Plane



Failure Plane

MRD FORM 738
1 APR 64

FIGURE 72



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 128 , MRD Lab. No. 64/90
Core Depth 303.8-304.9 feet
Core Diam. 2.411 in., Core Ht. 4.80 in.
Core Weight, SSD , 954.9 gm.

	Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6psi,
①	3,000	2.50
②	6,000	5.18
③	10,000	6.67
④		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with fine-to medium-grained groundmass. One large feldspar crystal of 1½-in. length occurs within an end section of the core specimen.

In triaxial compression, multi-stage, the core slid on the sawed joint which dipped at 45 degrees. Slight granulation of mineral grains and faint slickensides were observed along the joint plane surfaces.

MRD FORM
1 APR 64 737

FIGURE 73

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

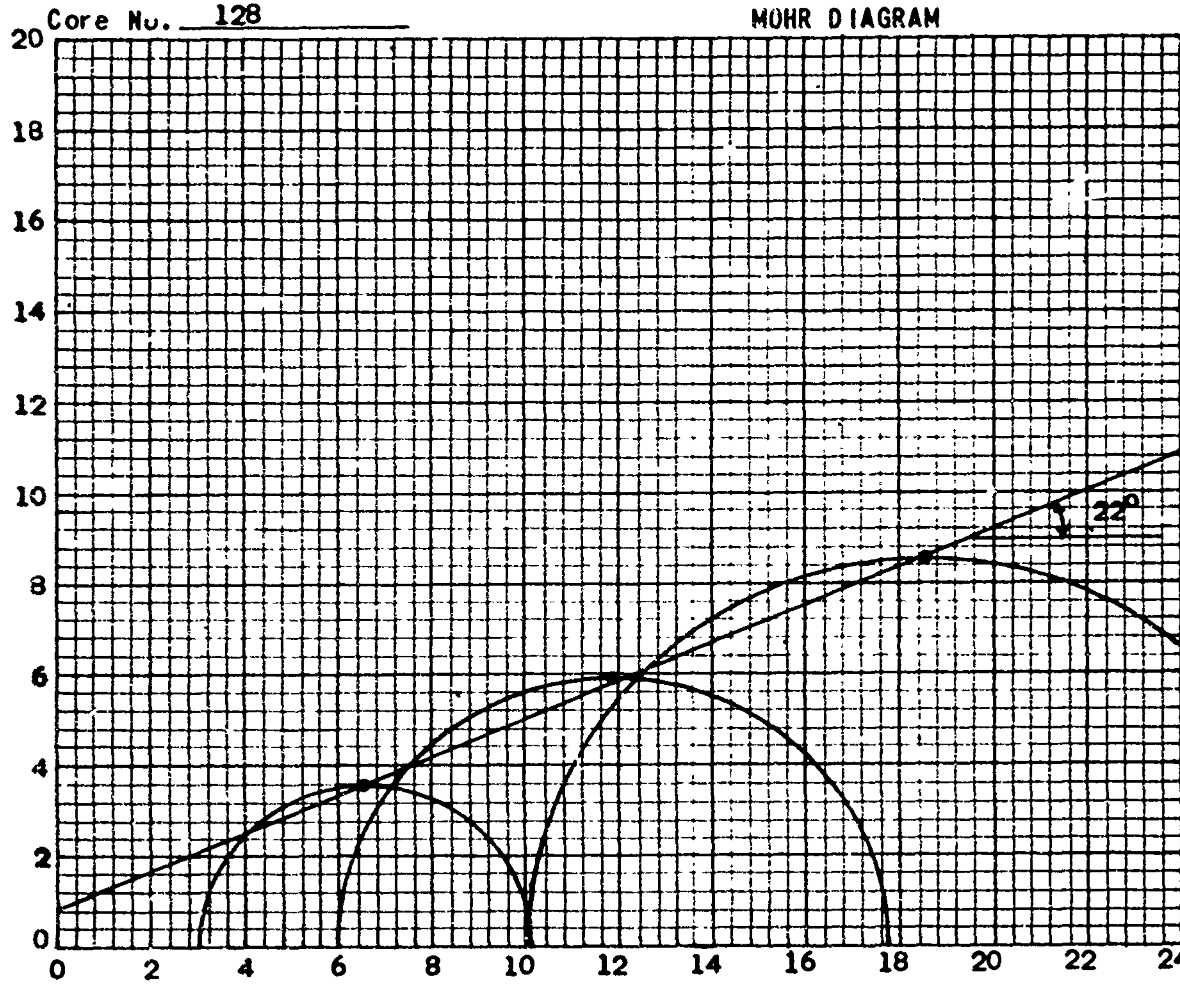
TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 128

MOHR DIAGRAM

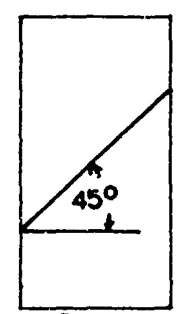
MRD Lab. No. 64/90

PILEDRIVER

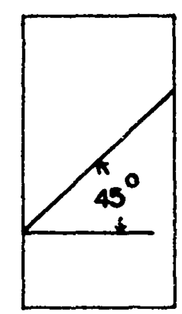


Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Sawed Joint Plane	Normal Stress (σ), psi Failure Plane
3,000	10,060	6,560	6,560
6,000	17,763	11,882	11,882
10,000	27,087	18,544	18,544

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Sawed Joint Plane	Shear Stress (τ), psi Failure Plane
3,000	10,060	3,560	3,560
6,000	17,763	5,882	5,882
10,000	27,087	8,544	8,544



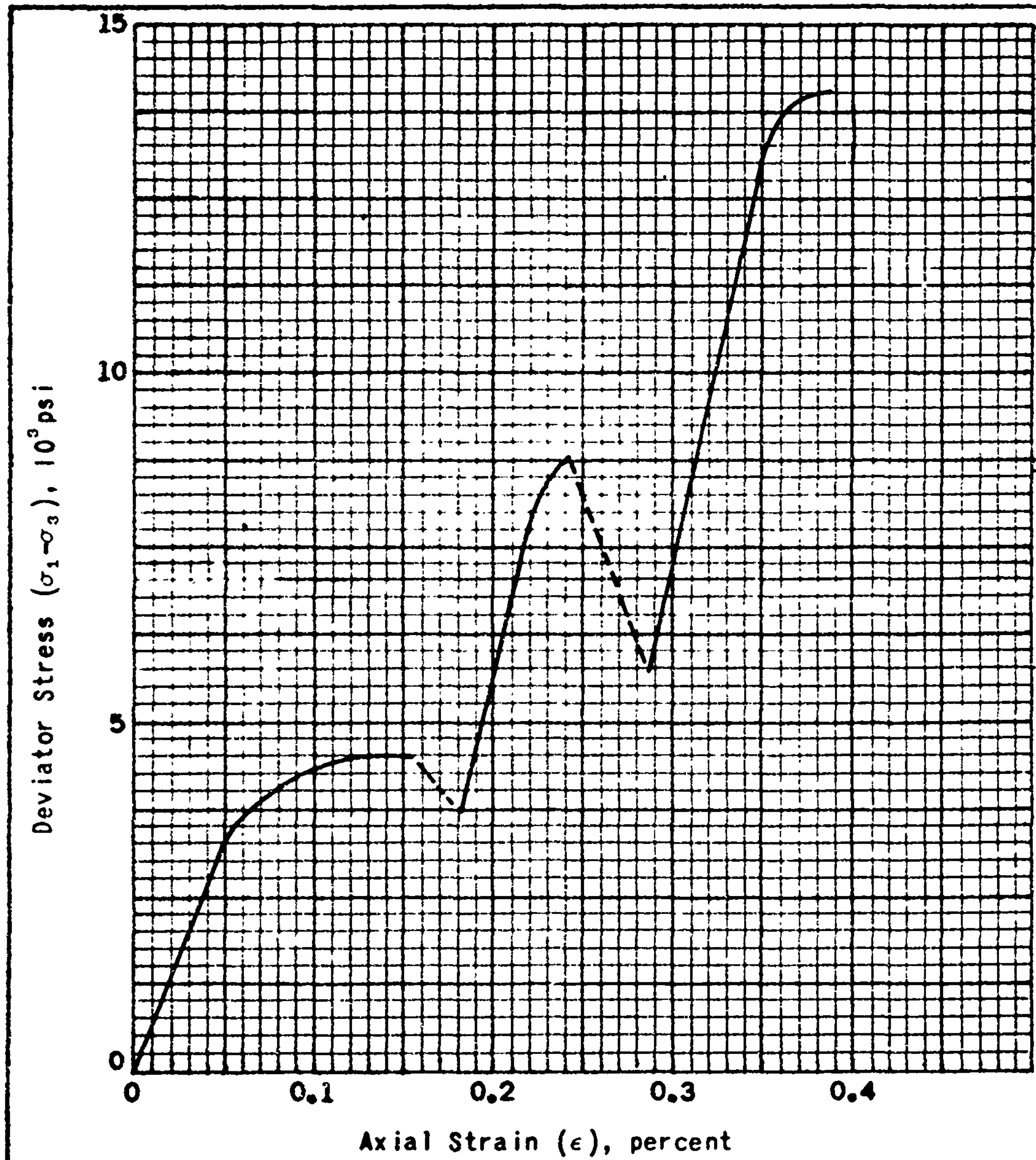
Sawed Joint Plane



Failure Plane

MRD FORM
1 APR 64 738

FIGURE 74



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 129, MRD Lab. No. 64/90
Core Depth 475.7-476.4 feet
Core Diam. 2.402 in., Core Ht. 4.86 in.
Core Weight, SSD . 960.9 gm.

	Confining Pressure (σ_3), psi.	Modulus of Elasticity, 10^6 psi.
1	3,000	6.57
2	6,000	10.70
3	10,000	11.45
4		

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with fine-grained groundmass. One large pink feldspar crystal of 1½-in. length occurs in an end section of the core specimen.

In triaxial compression, multi-stage, the core slid on the sawed joint which dipped at 55 degrees. Slight granulation of mineral grains and faint slickensides were noted along the joint plane surfaces.

MRD FORM
1 APR 64 737

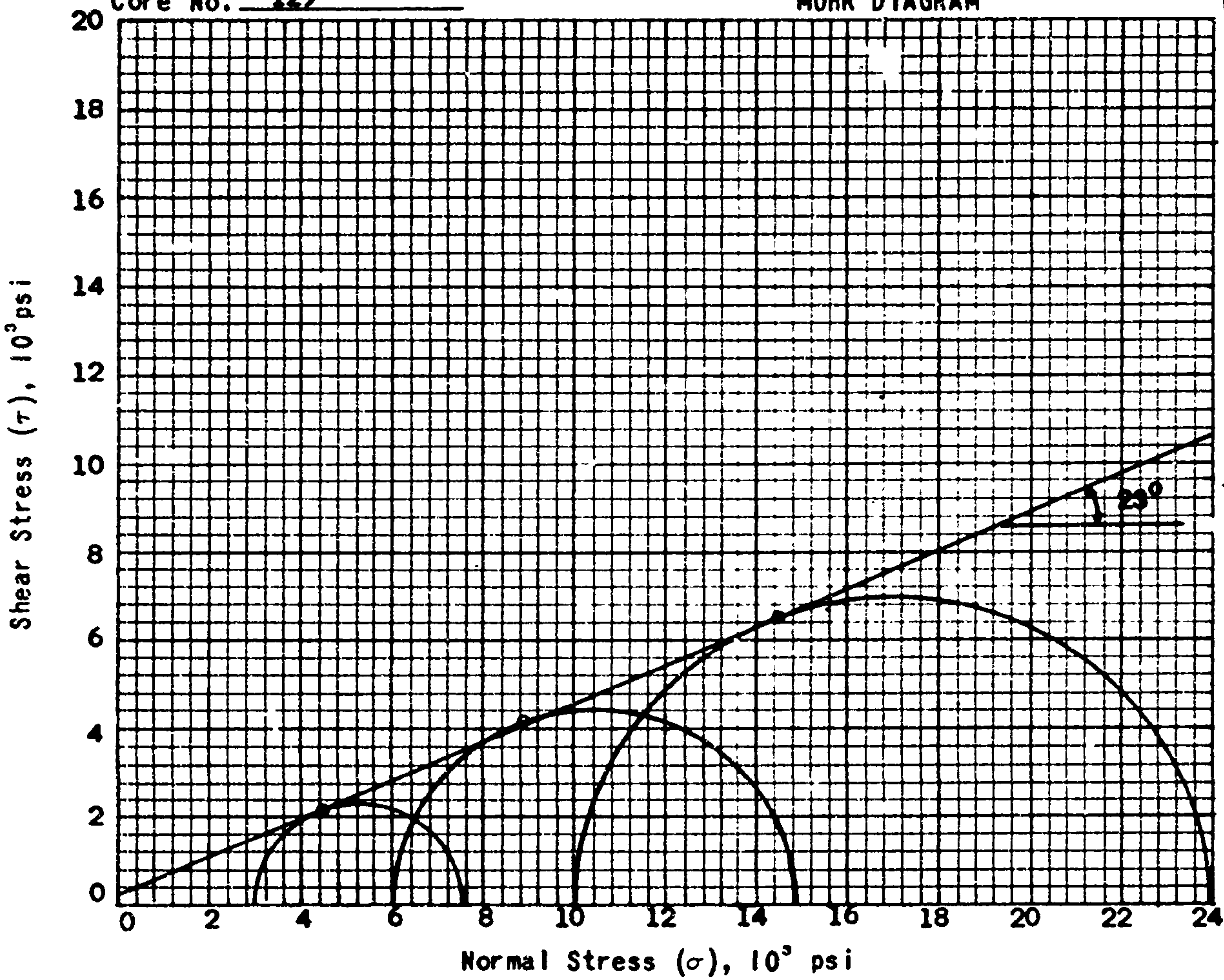
FIGURE 75

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 129

MOHR DIAGRAM

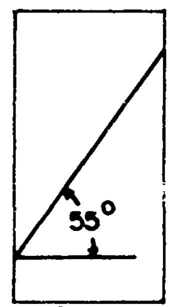


MRD Lab. No. 64/90

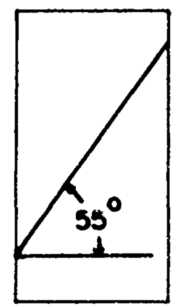
PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Sawed Joint Plane ○	Normal Stress (σ), psi Failure Plane ○
3,000	7,570	4,500	4,500
6,000	14,830	8,910	8,910
10,000	23,910	14,580	14,580

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Sawed Joint Plane ○	Shear Stress (τ), psi Failure Plane ○
3,000	7,570	2,150	2,150
6,000	14,830	4,150	4,150
10,000	23,910	6,540	6,540



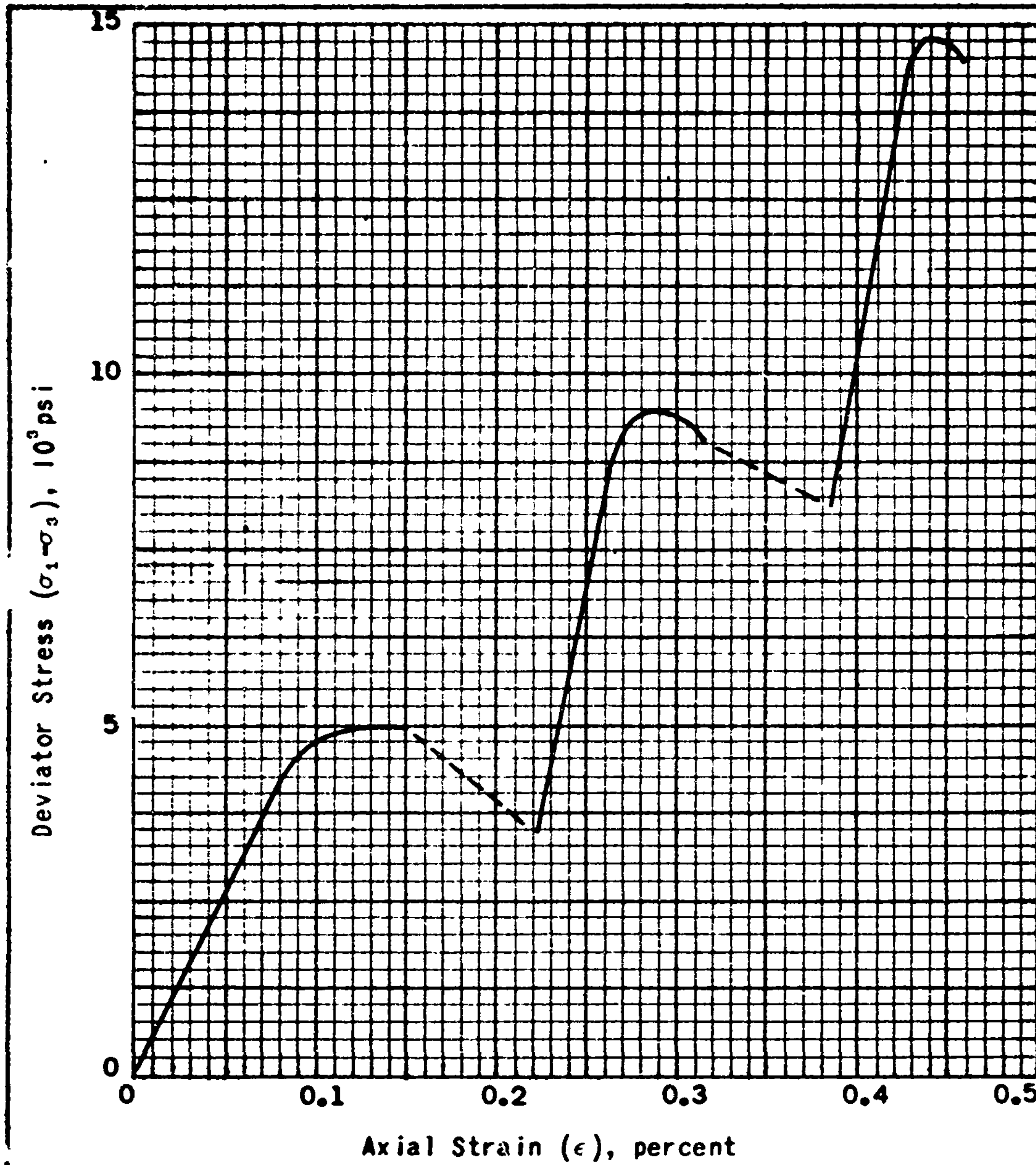
Sawed Joint Plane



Failure Plane

MRD FORM
1 APR 64 738

FIGURE 76



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

STRESS-STRAIN RELATIONSHIP

PILEDRIVER

Core No. 35, MRD Lab. No. 64/90
Core Depth 432.6-433.7 feet
Core Diam. 2.395 in., Core Ht. 4.94 in.
Core Weight, SSD, 974.7 gm.

Confining Pressure (σ_3), psi,	Modulus of Elasticity, 10^6psi,
① 3,000	5.25
② 6,000	12.67
③ 10,000	15.10
④	

Approximate Rate of Strain, 0.001 in./min.

Core Specimen Description:

Quartz Monzonite, light gray, porphyritic with medium-grained groundmass. Several large feldspar crystals of 3/4-in. length occur near one end of the core specimen.

In triaxial compression, multi-stage, the core slid on the sawed joint which dipped at 62 degrees. Slight granulation of mineral grains and faint slickensides were observed along the joint plane surfaces.

MRD FORM
1 APR 64 737

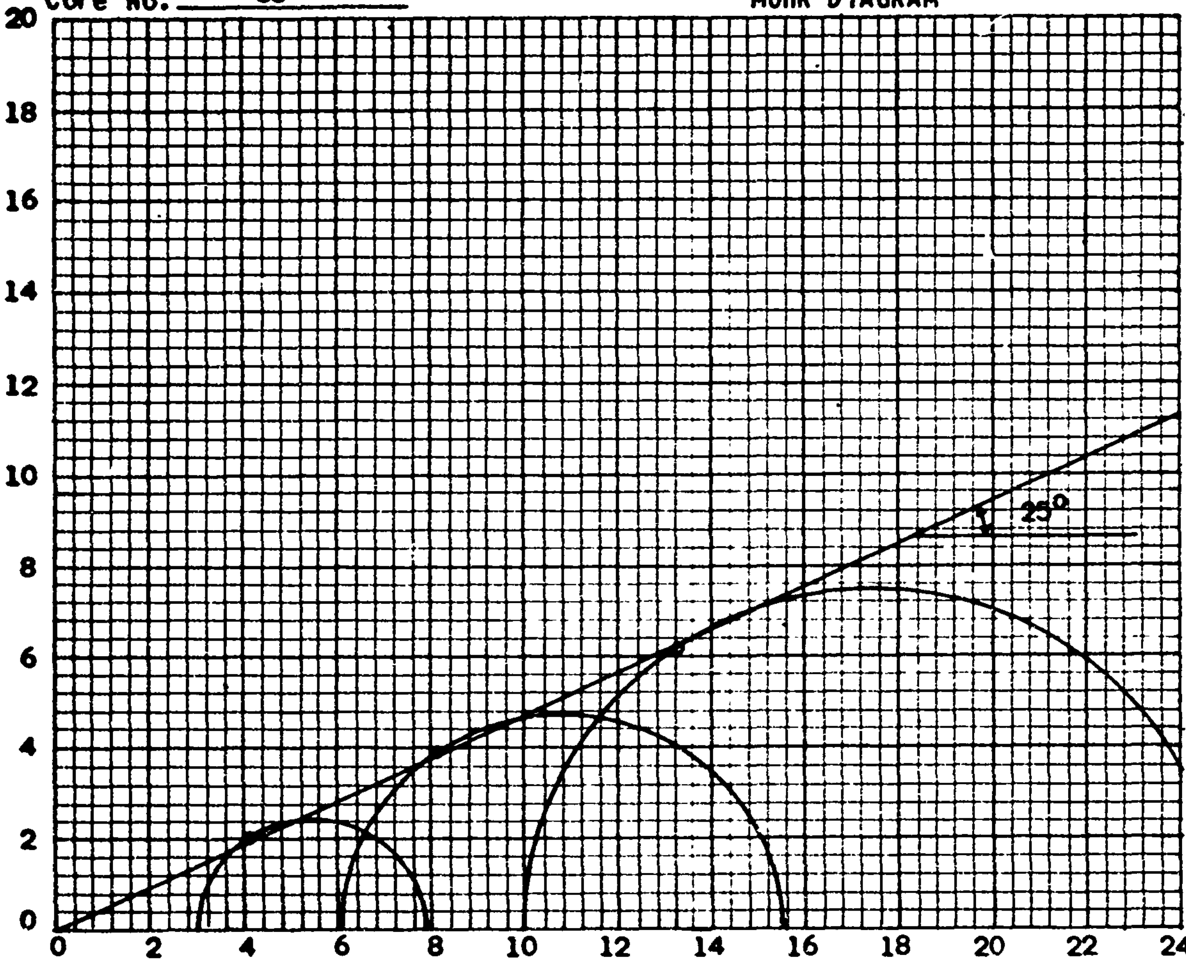
FIGURE 77

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TRIAXIAL COMPRESSION TEST OF ROCK

Core No. 35

MOHR DIAGRAM

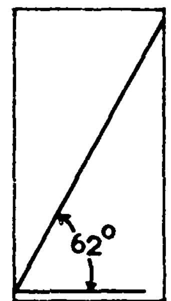


MRD Lab. No. 64/90

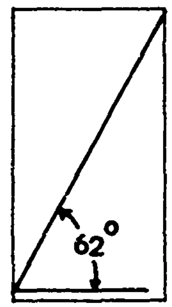
PILEDRIVER

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Normal Stress (σ), psi Sawed Joint Plane ○	Failure Plane ○
3,000	7,900	4,080	4,080
6,000	15,470	8,080	8,080
10,000	24,740	13,240	13,240

Confining Pressure, (σ_3), psi	Max. Prin. Stress (σ_1), psi	Shear Stress (τ), psi Sawed Joint Plane ○	Failure Plane ○
3,000	7,900	2,030	2,030
6,000	15,470	3,920	3,920
10,000	24,740	6,100	6,100



Sawed Joint Plane



Failure Plane

MRD FORM
1 APR 64 738

FIGURE 78

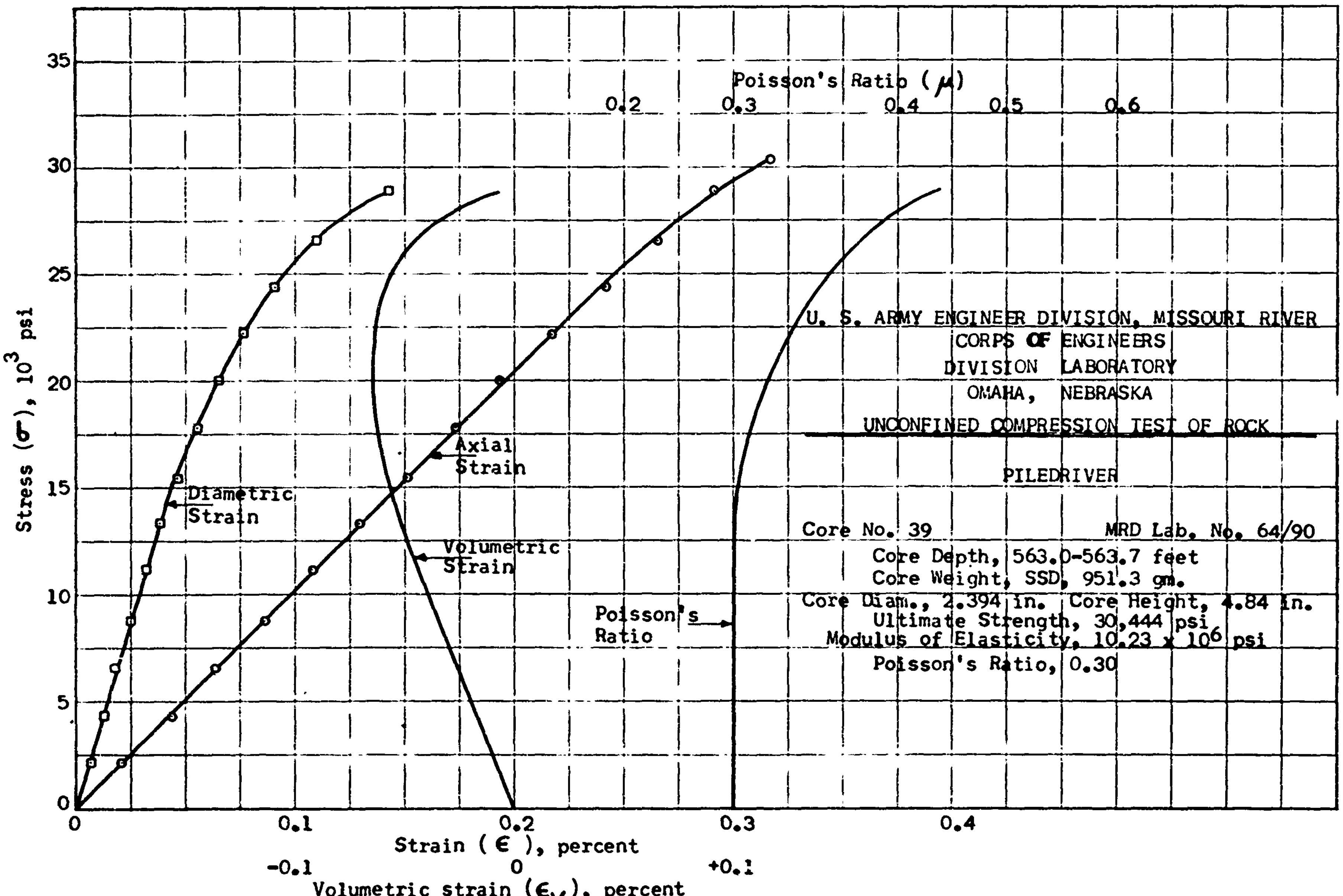
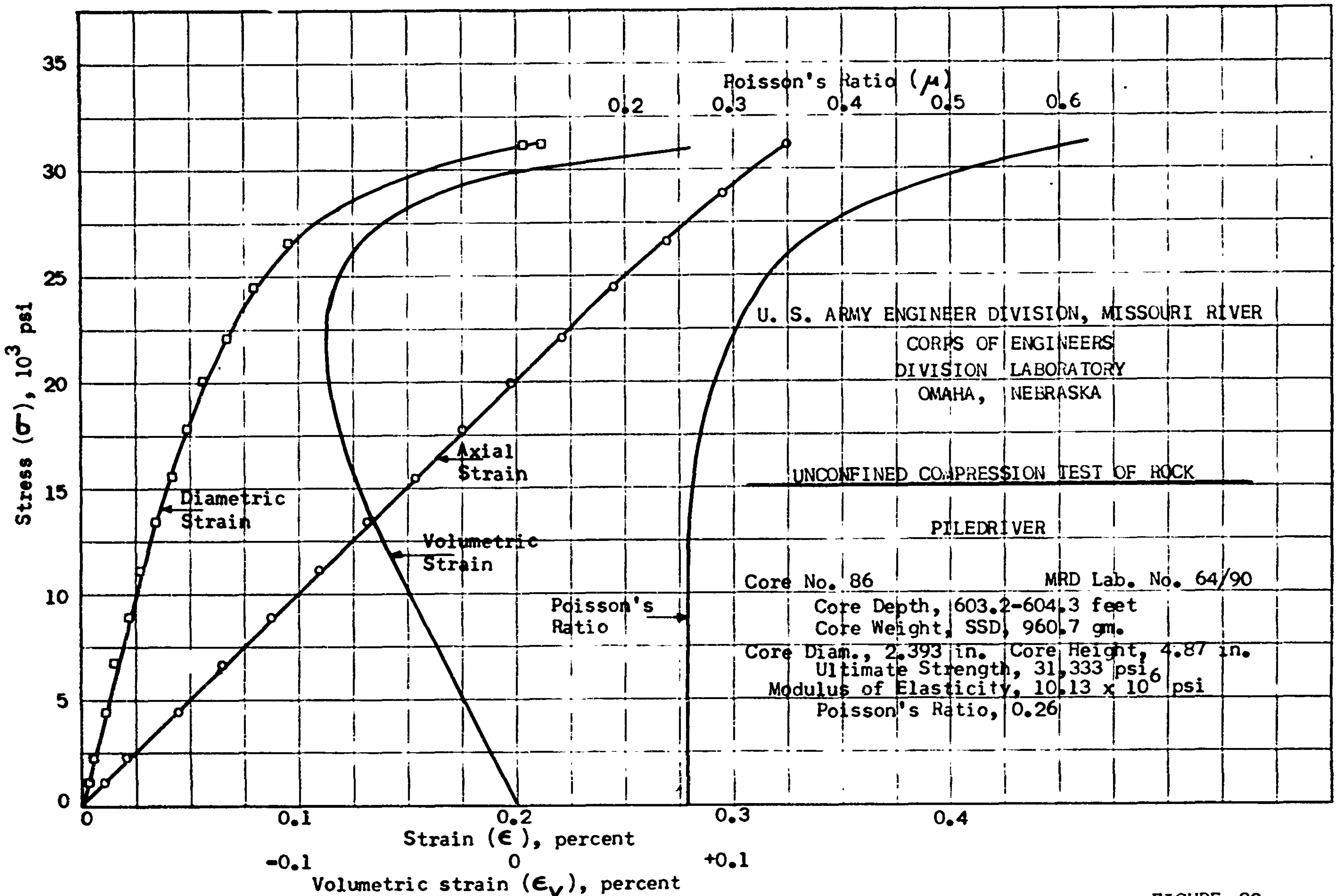
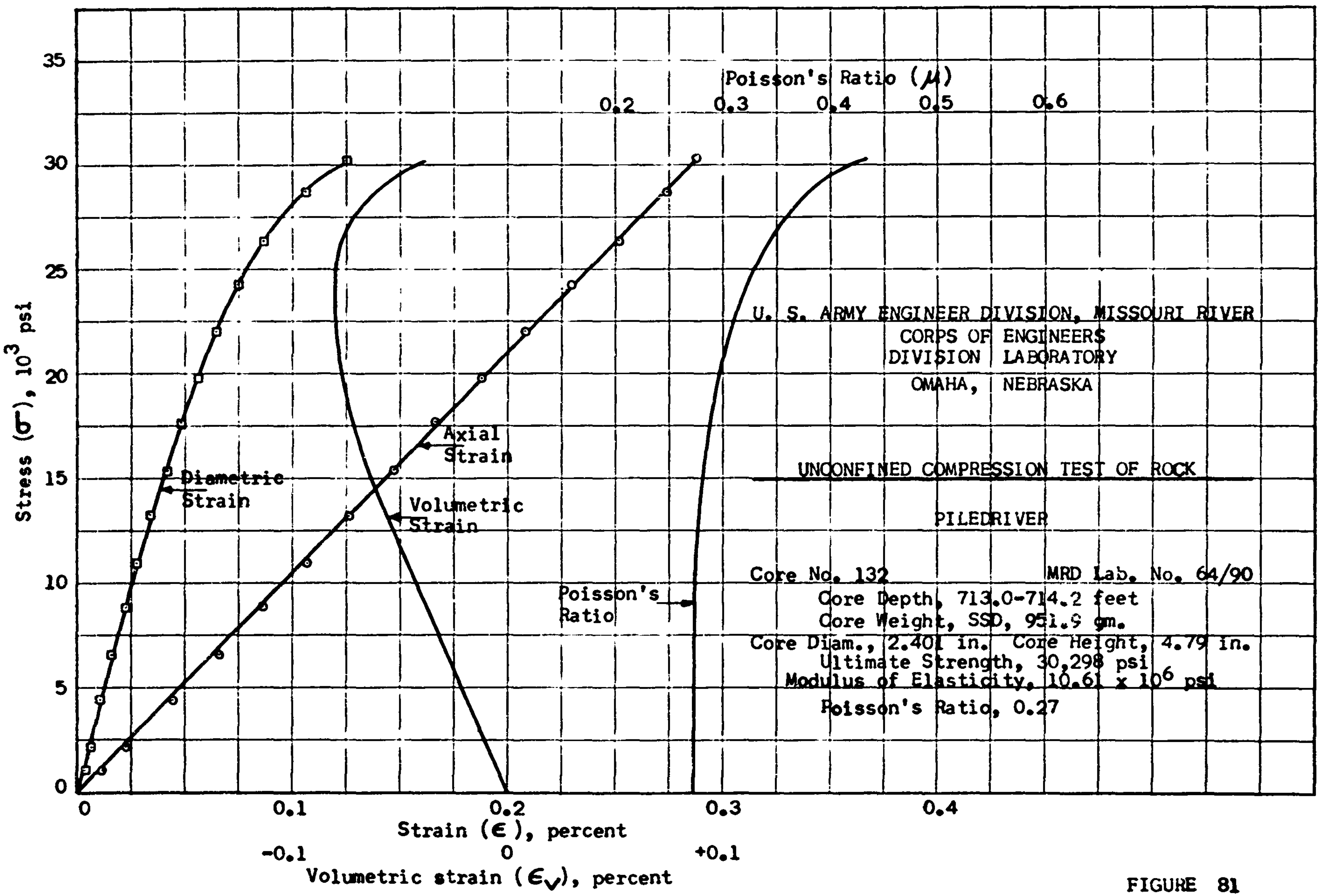

Poisson's Ratio (μ)
0.2
0.3
0.4
0.5
0.6
35
30
25
20
15
10
5
0
Stress (σ), 10^3 psi
Diametric Strain
Axial Strain
Volumetric Strain
Poisson's Ratio
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA
UNCONFINED COMPRESSION TEST OF ROCK
PILEDRIVER
Core No. 39
MRD Lab. No. 64/90
Core Depth, 563.0-563.7 feet
Core Weight, SSD, 951.3 gm.
Core Diam., 2.394 in. Core Height, 4.84 in.
Ultimate Strength, 30,444 psi
Modulus of Elasticity, 10.23 x 10^6 psi
Poisson's Ratio, 0.30
0
0.1
0.2
0.3
0.4
Strain (ϵ), percent
-0.1
0
+0.1
Volumetric strain (ϵ_v), percent

FIGURE 79



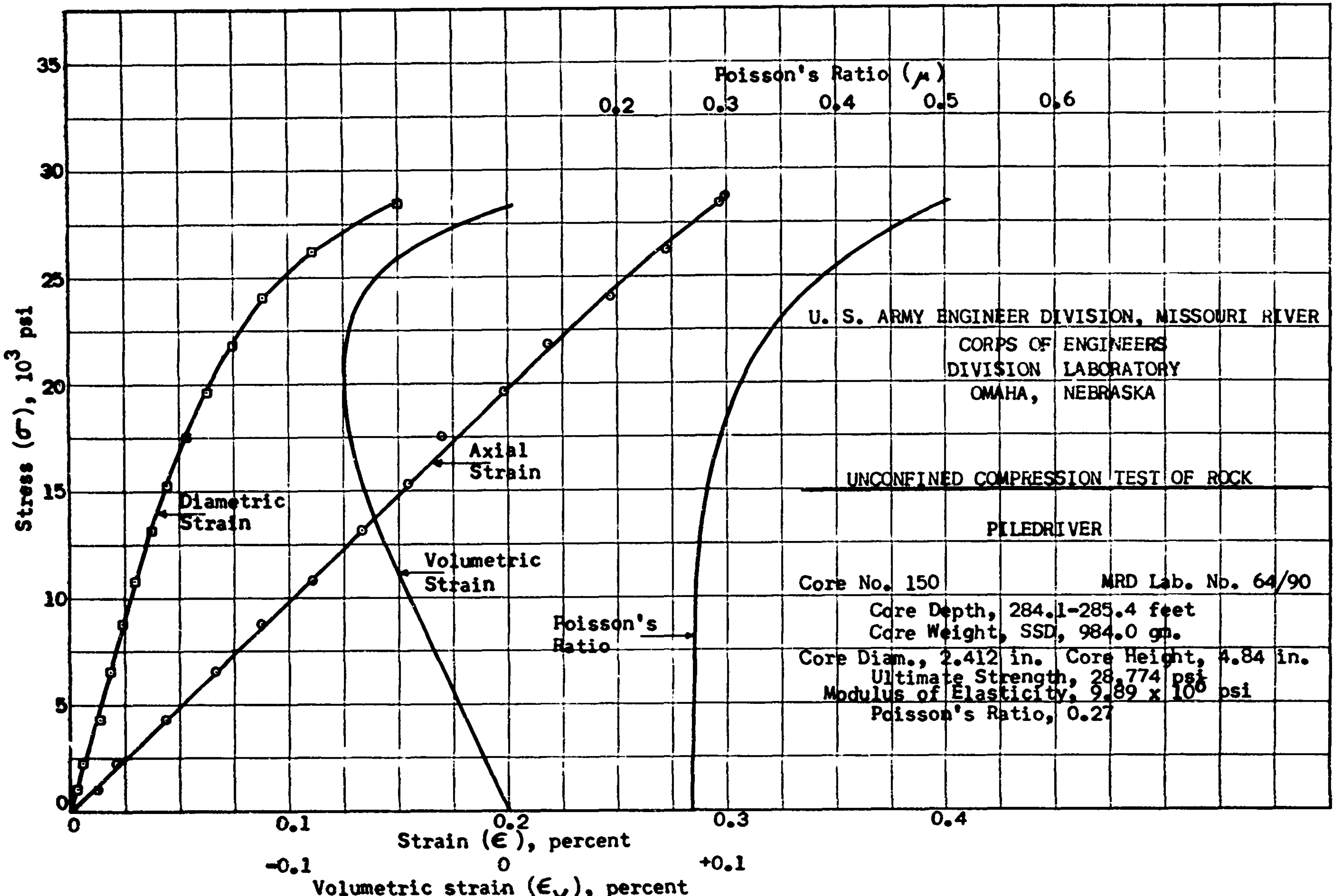
Stress (σ), 10^3 psi
35
30
25
20
15
10
5
0
0
0.1
0.2
0.3
0.4
Strain (ϵ), percent
-0.1
0
+0.1
Volumetric strain (ϵ_v), percent
Poisson's Ratio (μ)
0.2
0.3
0.4
0.5
0.6
Diametric Strain
Axial Strain
Volumetric Strain
Poisson's Ratio
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA
UNCONFINED COMPRESSION TEST OF ROCK
PILEDRIVER
Core No. 86
MRD Lab. No. 64/90
Core Depth, 603.2-604.3 feet
Core Weight, SSD, 960.7 gm.
Core Diam., 2.393 in. Core Height, 4.87 in.
Ultimate Strength, 31,333 psi
Modulus of Elasticity, 10.13 x 10^6 psi
Poisson's Ratio, 0.26

FIGURE 80



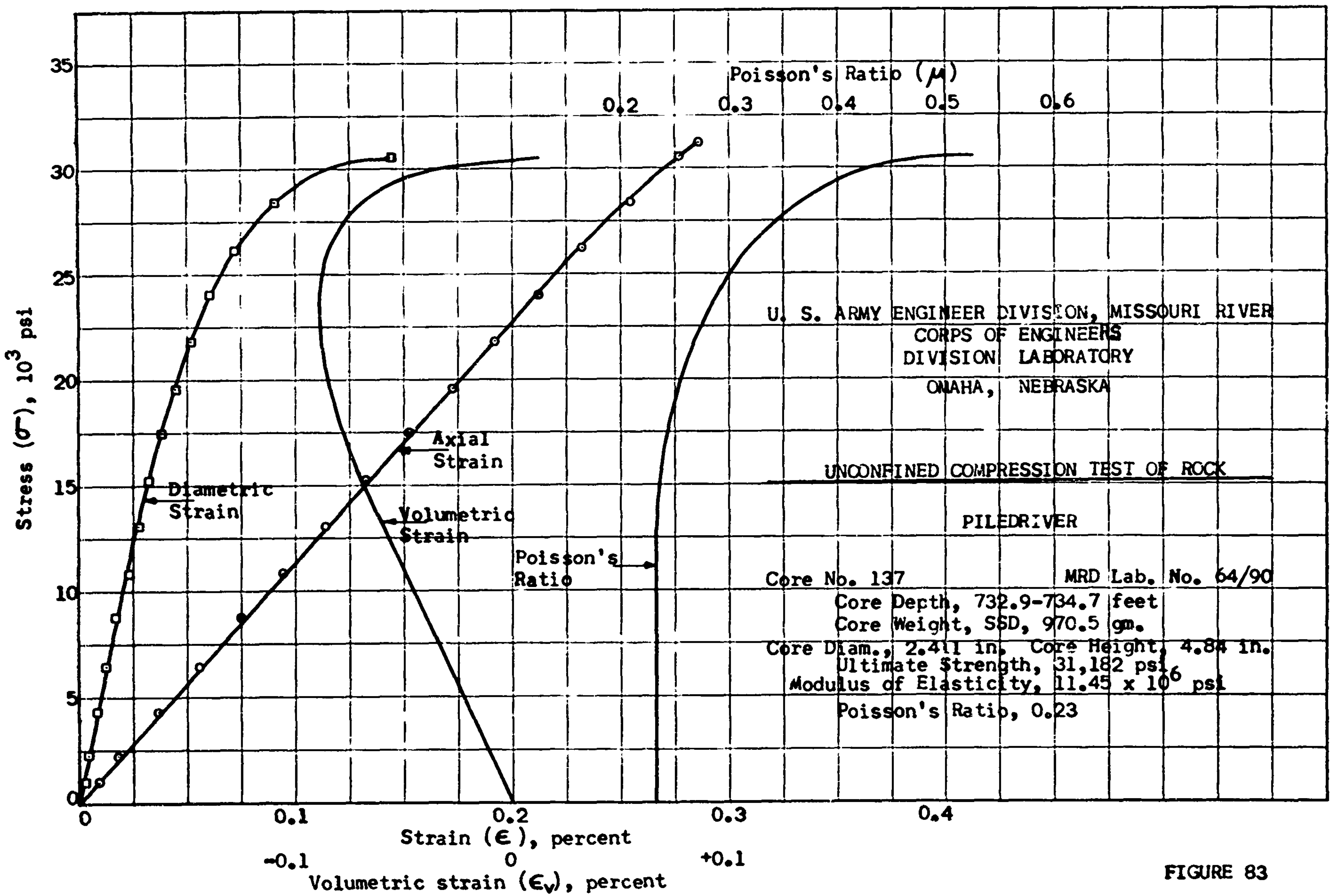
Poisson's Ratio (μ)
0.2
0.3
0.4
0.5
0.6
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA
UNCONFINED COMPRESSION TEST OF ROCK
PILEDRIVER
Core No. 132
MRD Lab. No. 64/90
Core Depth, 713.0-714.2 feet
Core Weight, SSD, 951.9 gm.
Core Diam., 2.401 in. Core Height, 4.79 in.
Ultimate Strength, 30,298 psi
Modulus of Elasticity, 10.61 x 10^6 psi
Poisson's Ratio, 0.27
Diametric Strain
Axial Strain
Volumetric Strain
Poisson's Ratio
Stress (σ), 10^3 psi
0
5
10
15
20
25
30
35
0
0.1
0.2
0.3
0.4
Strain (ε), percent
-0.1
0
+0.1
Volumetric strain (εv), percent

FIGURE 81



Poisson's Ratio (μ)
0.2
0.3
0.4
0.5
0.6
35
30
25
20
15
10
5
0
Stress (σ), 10^3 psi
Diametric Strain
Axial Strain
Volumetric Strain
Poisson's Ratio
0.1
0.2
0.3
0.4
Strain (ϵ), percent
-0.1
+0.1
Volumetric strain (ϵ_v), percent
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA
UNCONFINED COMPRESSION TEST OF ROCK
PILEDRIVER
Core No. 150
MRD Lab. No. 64/90
Core Depth, 284.1-285.4 feet
Core Weight, SSD, 984.0 gm.
Core Diam., 2.412 in. Core Height, 4.84 in.
Ultimate Strength, 28,774 psi
Modulus of Elasticity, 9.89 x 10^6 psi
Poisson's Ratio, 0.27

FIGURE 82



Poisson's Ratio (μ)
0.2
0.3
0.4
0.5
0.6
35
30
25
20
15
10
5
0
Stress (σ), 10^3 psi
0.1
0.2
0.3
0.4
Strain (ϵ), percent
-0.1
0
+0.1
Volumetric strain (ϵ_v), percent
Diametric Strain
Axial Strain
Volumetric Strain
Poisson's Ratio
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA
UNCONFINED COMPRESSION TEST OF ROCK
PILEDRIVER
Core No. 137
MRD Lab. No. 64/90
Core Depth, 732.9-734.7 feet
Core Weight, SSD, 970.5 gm.
Core Diam., 2.411 in. Core Height, 4.84 in.
Ultimate Strength, 31,182 psi
Modulus of Elasticity, 11.45 x 10^6 psi
Poisson's Ratio, 0.23

FIGURE 83

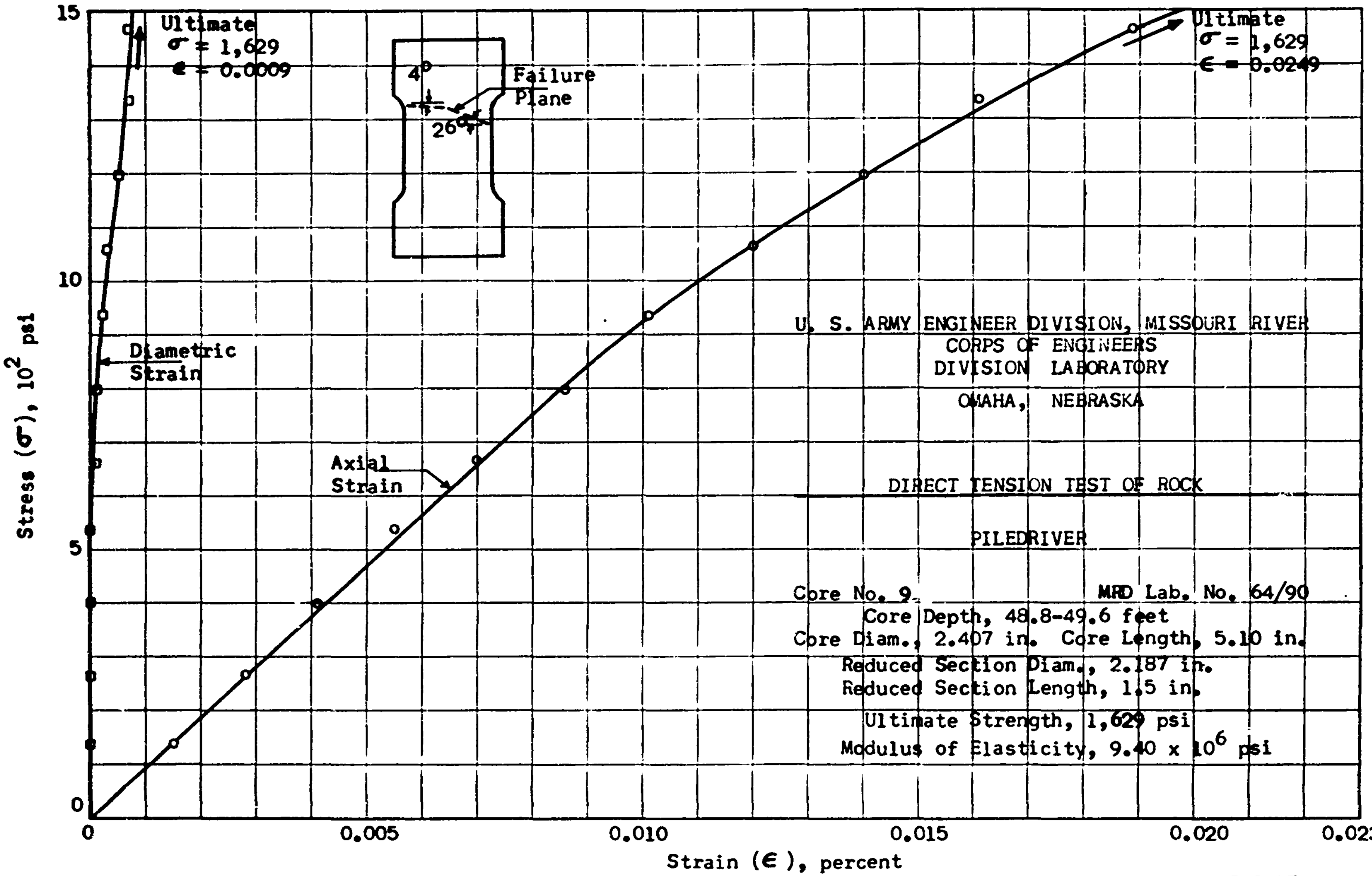
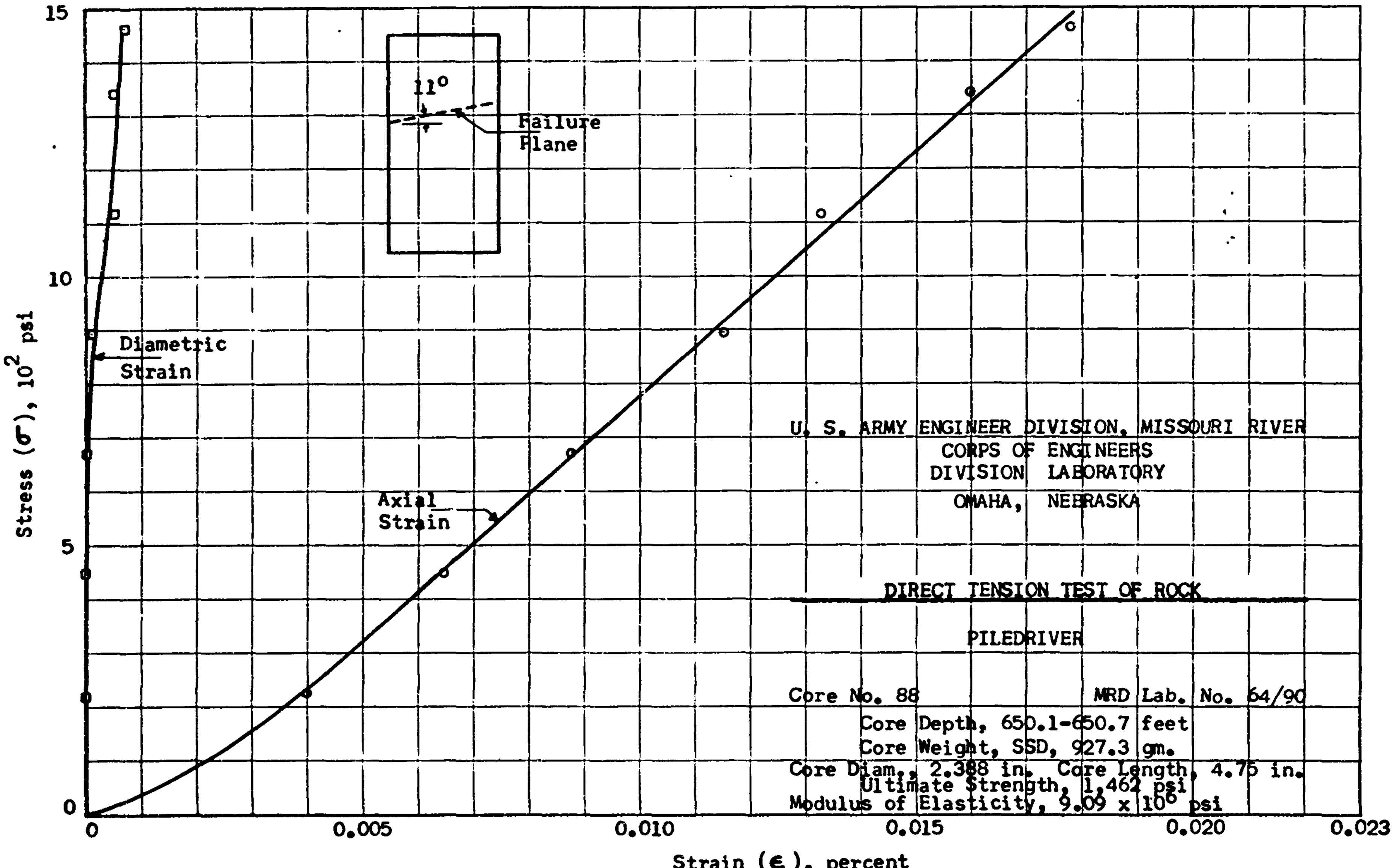

Ultimate
σ = 1,629
ε = 0.0009
Failure Plane
4°
26°
Diametric Strain
Axial Strain
Ultimate
σ = 1,629
ε = 0.0249
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA
DIRECT TENSION TEST OF ROCK
PILEDRIVER
Core No. 9
MRD Lab. No. 64/90
Core Depth, 48.8-49.6 feet
Core Diam., 2.407 in. Core Length, 5.10 in.
Reduced Section Diam., 2.187 in.
Reduced Section Length, 1.5 in.
Ultimate Strength, 1,629 psi
Modulus of Elasticity, 9.40 x 10^6 psi
Stress (σ), 10^2 psi
15
10
5
0
0
0.005
0.010
0.015
0.020
0.023
Strain (ε), percent

FIGURE 84



15
10
5
0
Stress (σ), 10² psi
0
0.005
0.010
0.015
0.020
0.023
Strain (ε), percent
11°
Failure Plane
Diametric Strain
Axial Strain
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA
DIRECT TENSION TEST OF ROCK
PILEDRIVER
Core No. 88
MRD Lab. No. 64/90
Core Depth, 650.1-650.7 feet
Core Weight, SSD, 927.3 gm.
Core Diam., 2.388 in. Core Length, 4.75 in.
Ultimate Strength, 1,462 psi
Modulus of Elasticity, 9.09 x 10⁶ psi

FIGURE 85

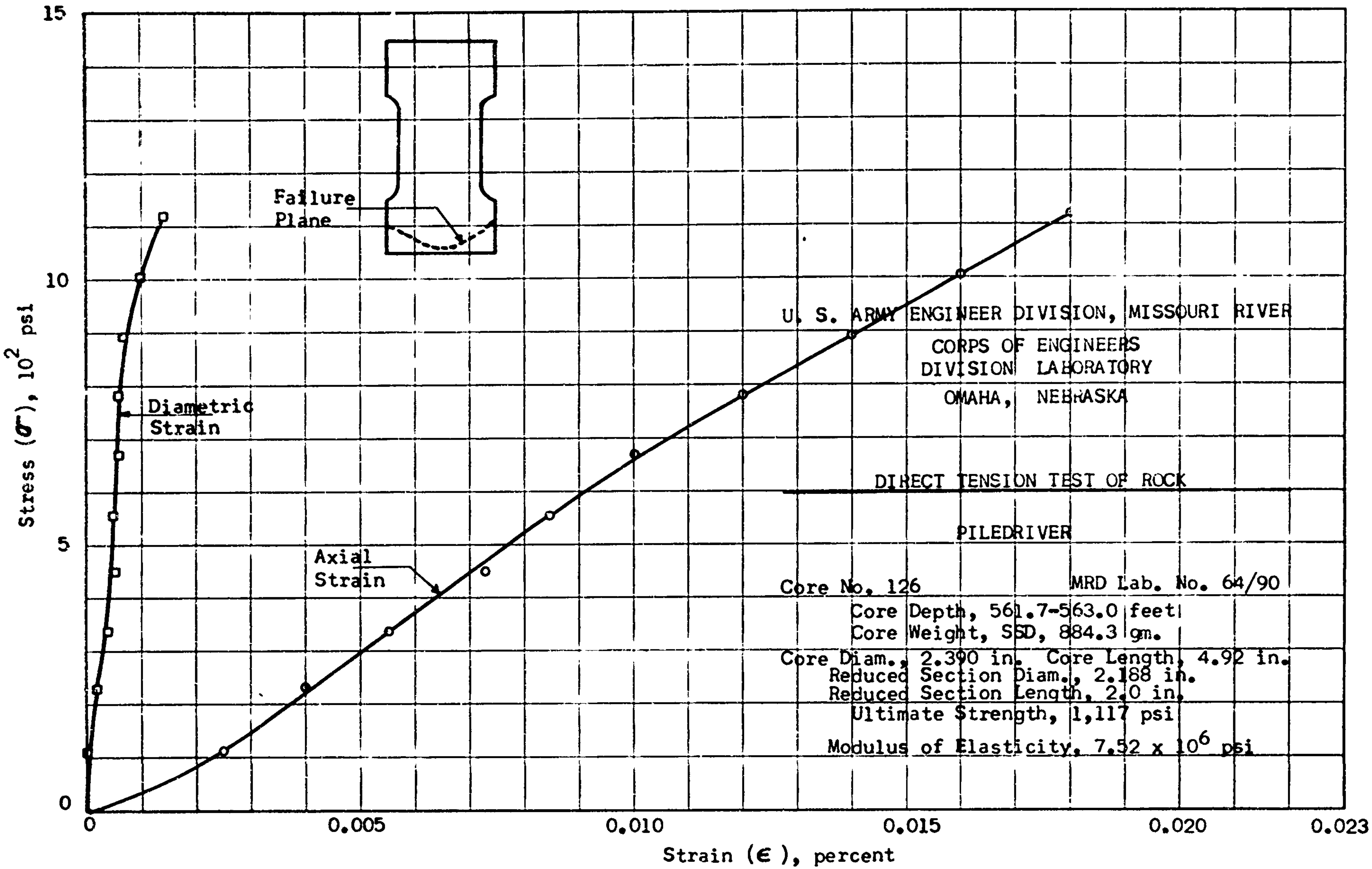
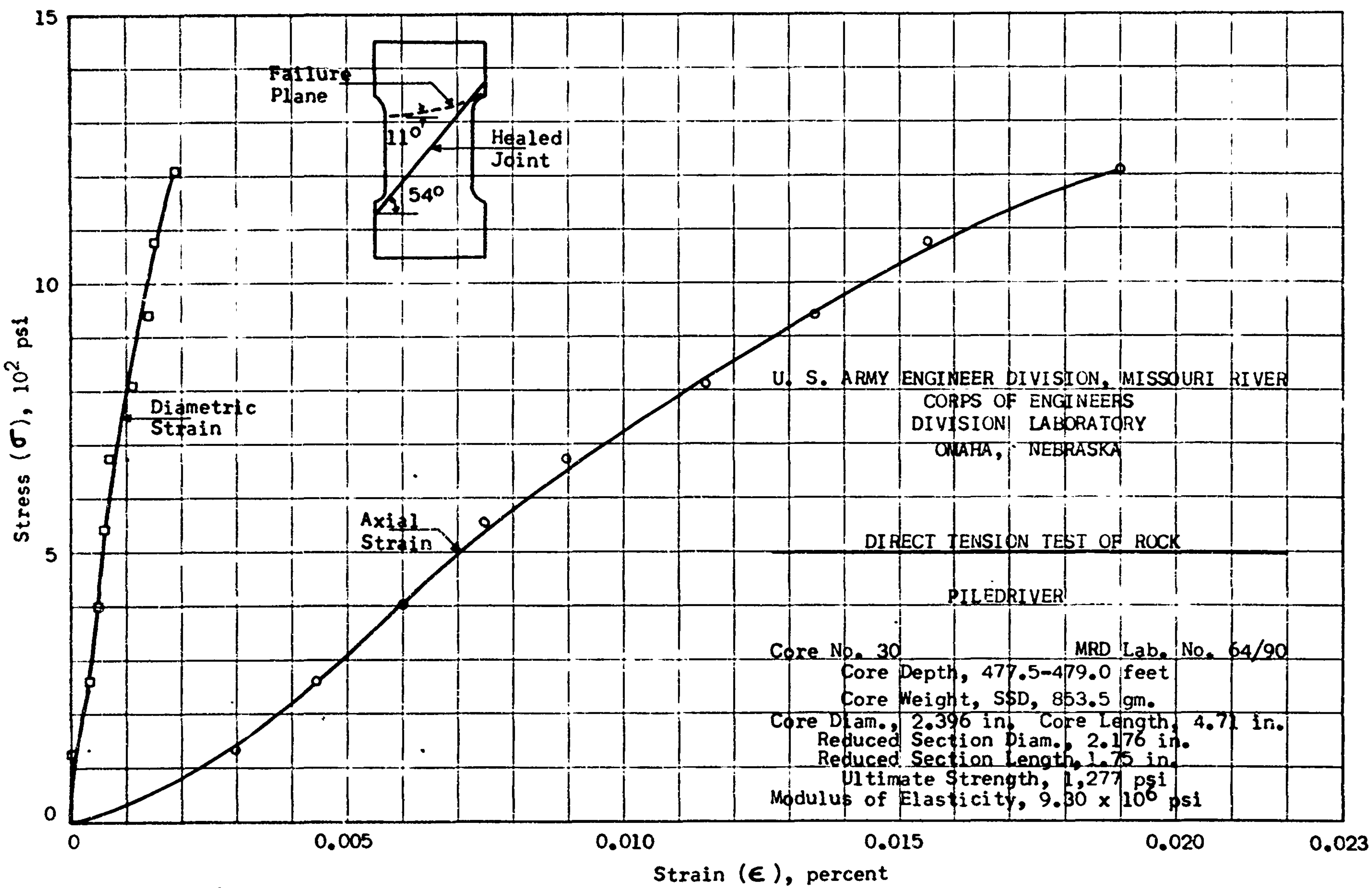
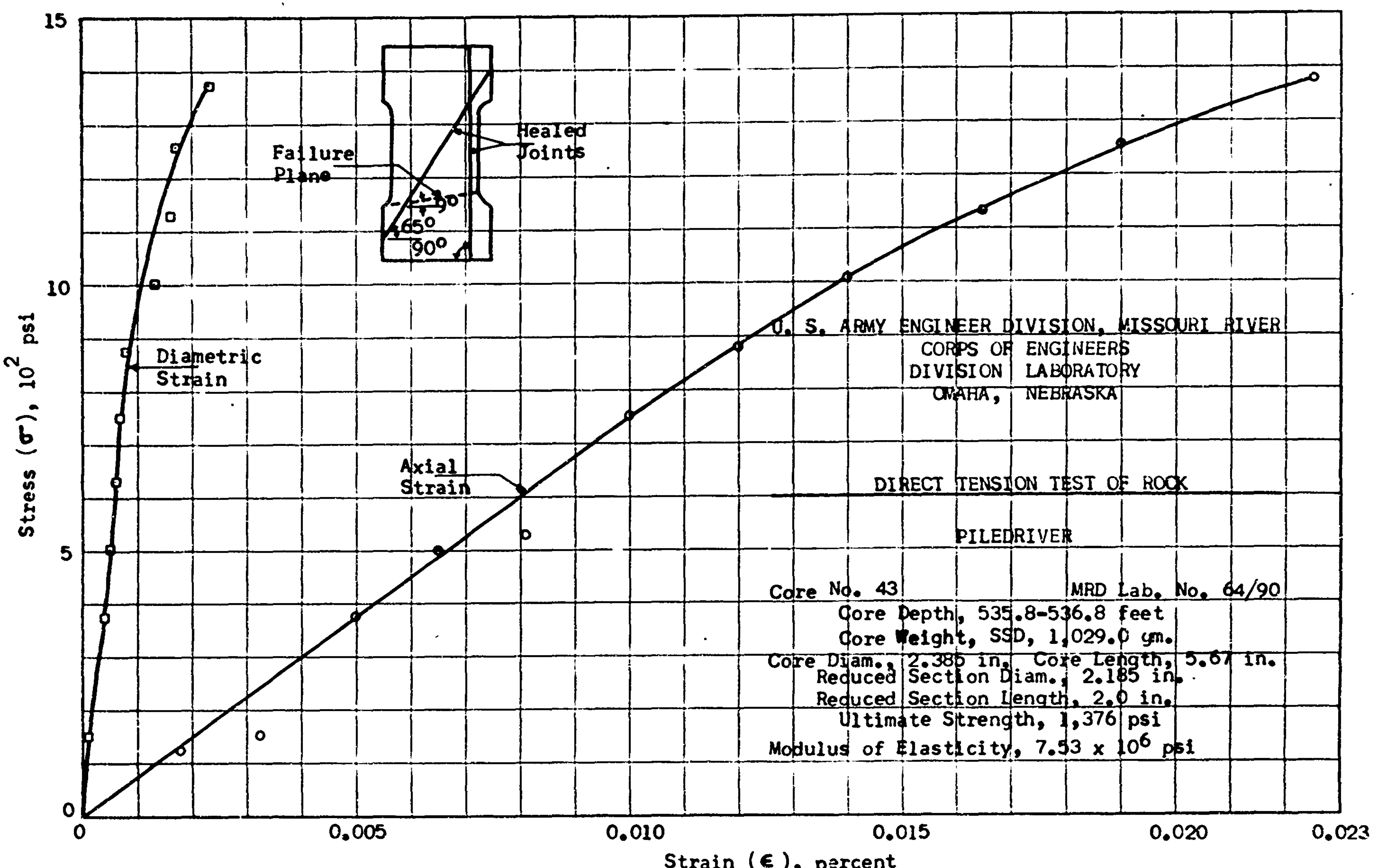

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA
DIRECT TENSION TEST OF ROCK
PILEDRIVER
Core No. 126
MRD Lab. No. 64/90
Core Depth, 561.7-563.0 feet
Core Weight, SSD, 884.3 gm.
Core Diam., 2.390 in. Core Length, 4.92 in.
Reduced Section Diam., 2.188 in.
Reduced Section Length, 2.0 in.
Ultimate Strength, 1,117 psi
Modulus of Elasticity, 7.52 x 10^6 psi
Failure Plane
Diametric Strain
Axial Strain
Stress (σ), 10^2 psi
15
10
5
0
0
0.005
0.010
0.015
0.020
0.023
Strain (ε), percent

FIGURE 86



15
10
5
0
Stress (σ), 10² psi
0
0.005
0.010
0.015
0.020
0.023
Strain (ε), percent
Failure Plane
11°
54°
Healed Joint
Diametric Strain
Axial Strain
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA
DIRECT TENSION TEST OF ROCK
PILEDRIVER
Core No. 30
MRD Lab. No. 64/90
Core Depth, 477.5-479.0 feet
Core Weight, SSD, 853.5 gm.
Core Diam., 2.396 in. Core Length, 4.71 in.
Reduced Section Diam., 2.176 in.
Reduced Section Length, 1.75 in.
Ultimate Strength, 1,277 psi
Modulus of Elasticity, 9.30 x 10⁶ psi

FIGURE 87



15
10
5
0
Stress (σ), 10² psi
0
0.005
0.010
0.015
0.020
0.023
Strain (ε), percent
Failure Plane
Healed Joints
65°
90°
Diametric Strain
Axial Strain
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA
DIRECT TENSION TEST OF ROCK
PILEDRIVER
Core No. 43
MRD Lab. No. 64/90
Core Depth, 535.8-536.8 feet
Core Weight, SSD, 1,029.0 gm.
Core Diam., 2.385 in. Core Length, 5.67 in.
Reduced Section Diam., 2.185 in.
Reduced Section Length, 2.0 in.
Ultimate Strength, 1,376 psi
Modulus of Elasticity, 7.53 x 10⁶ psi

FIGURE 88

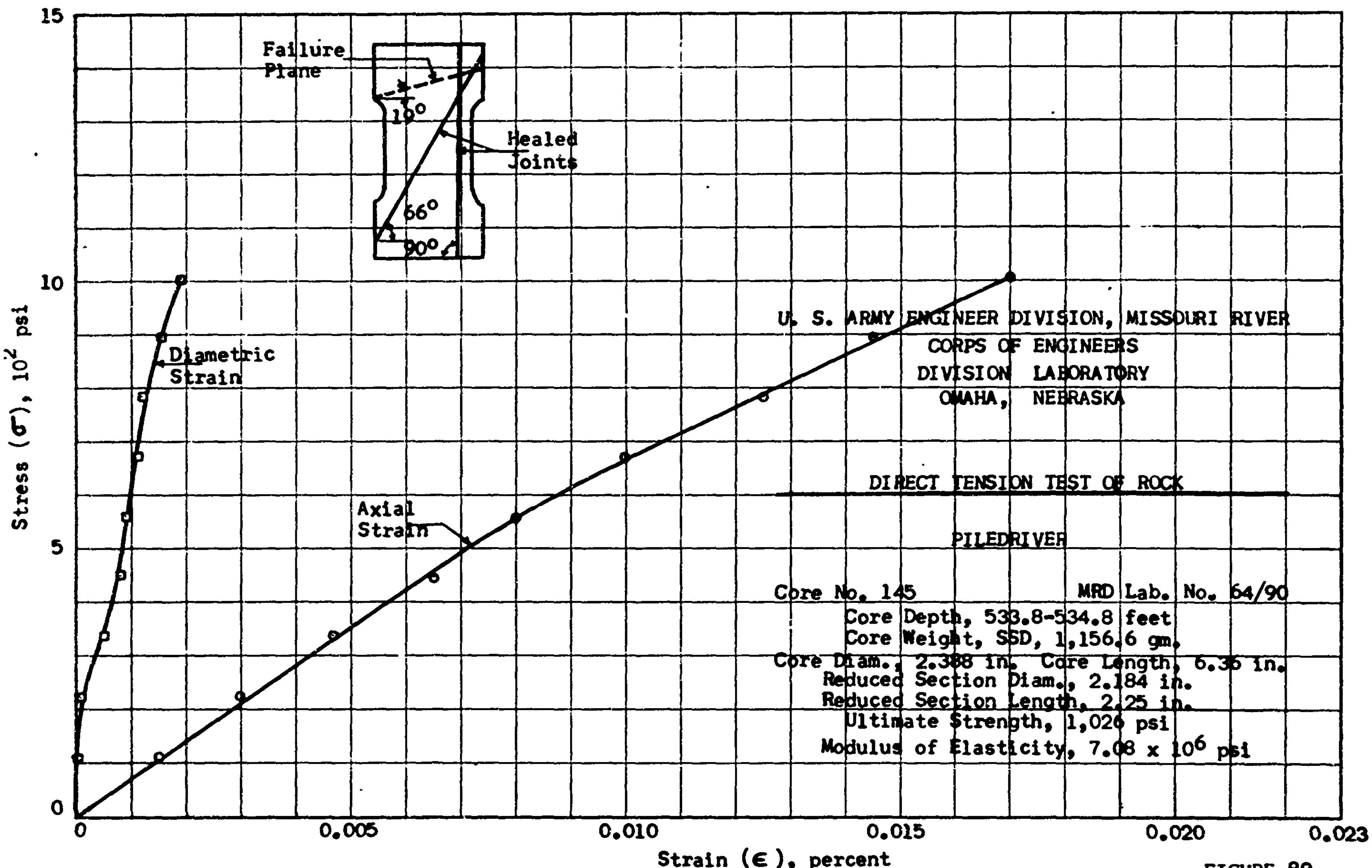
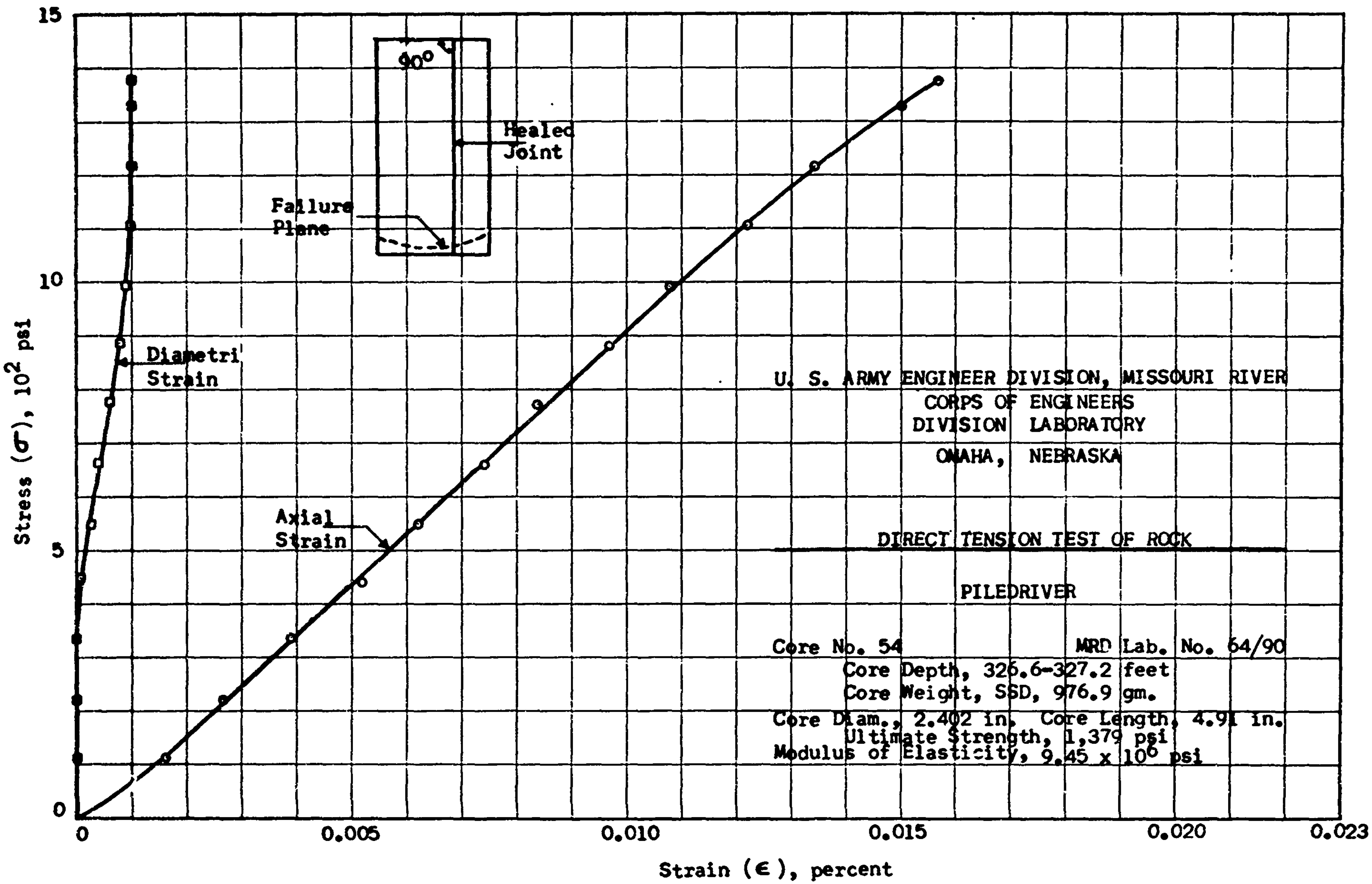
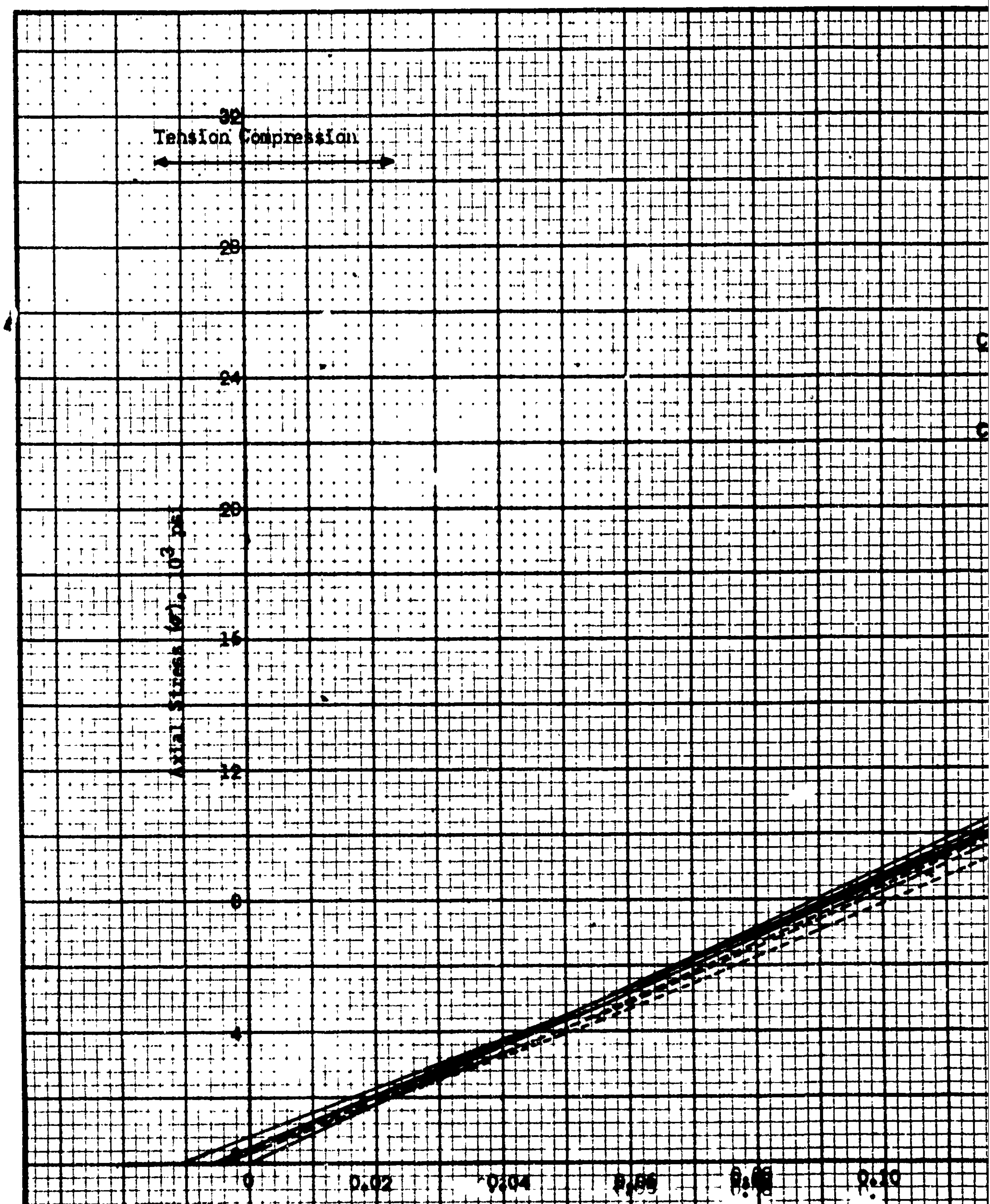

15
10
5
0
Stress (σ), 10² psi
0
0.005
0.010
0.015
0.020
0.023
Strain (∈), percent
Failure Plane
10°
Healed Joints
66°
90°
Diametric Strain
Axial Strain
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA
DIRECT TENSION TEST OF ROCK
PILEDRIVER
Core No. 145
MRD Lab. No. 64/90
Core Depth, 533.8-534.8 feet
Core Weight, SSD, 1,156.6 gm.
Core Diam., 2.388 in. Core Length, 6.36 in.
Reduced Section Diam., 2.184 in.
Reduced Section Length, 2.25 in.
Ultimate Strength, 1,026 psi
Modulus of Elasticity, 7.08 x 10⁶ psi

FIGURE 89



15
10
5
0
Stress (σ), 10^2 psi
0
0.005
0.010
0.015
0.020
0.023
Strain (ϵ), percent
90°
Healed Joint
Failure Plane
Diametri Strain
Axial Strain
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA
DIRECT TENSION TEST OF ROCK
PILEDRIVER
Core No. 54
MRD Lab. No. 64/90
Core Depth, 326.6-327.2 feet
Core Weight, SSD, 976.9 gm.
Core Diam., 2.402 in. Core Length, 4.91 in.
Ultimate Strength, 1,379 psi
Modulus of Elasticity, 9.45 x 10^6 psi

FIGURE 90

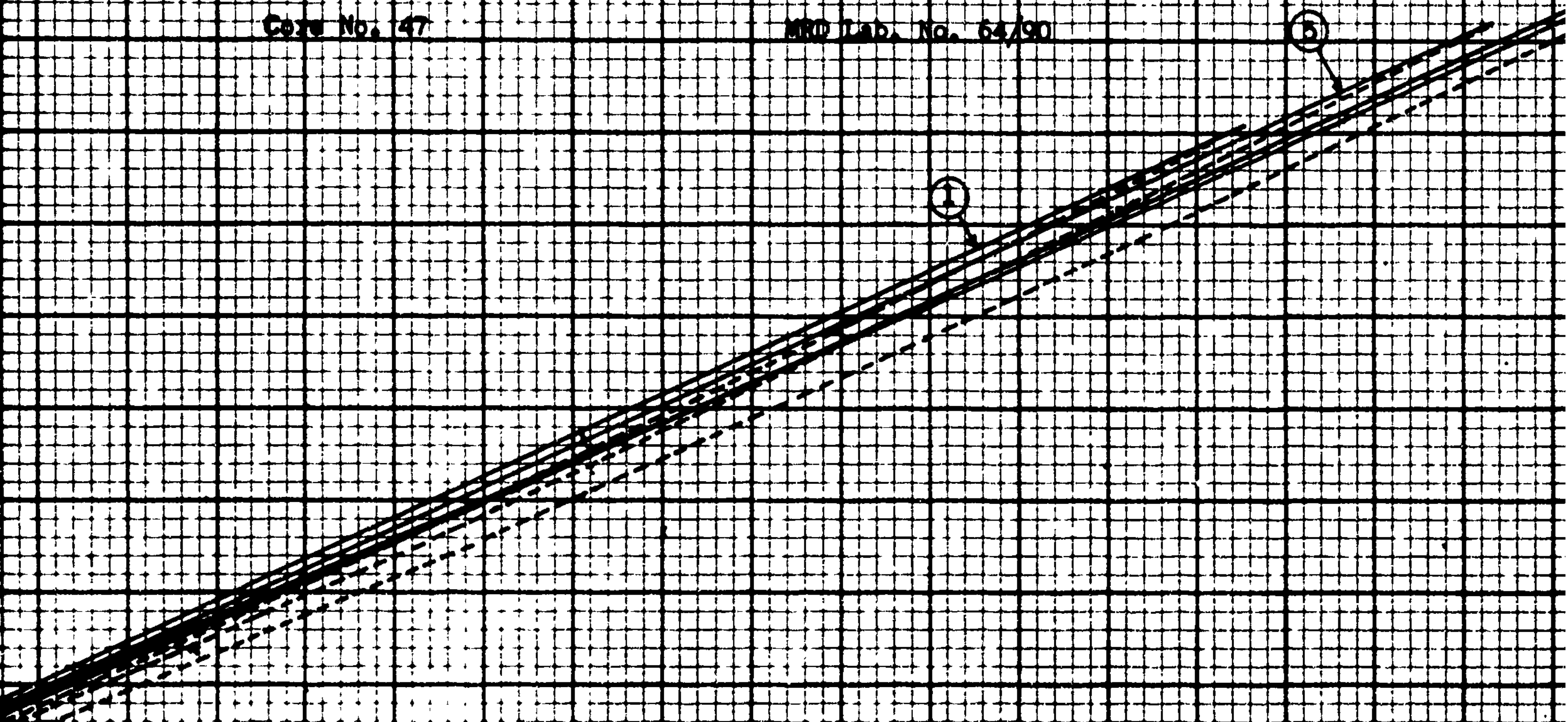

Tension Compression
32
28
24
20
16
12
8
4
0
0.02
0.04
0.10
Axial Stress (σ_1), 10^3 psi

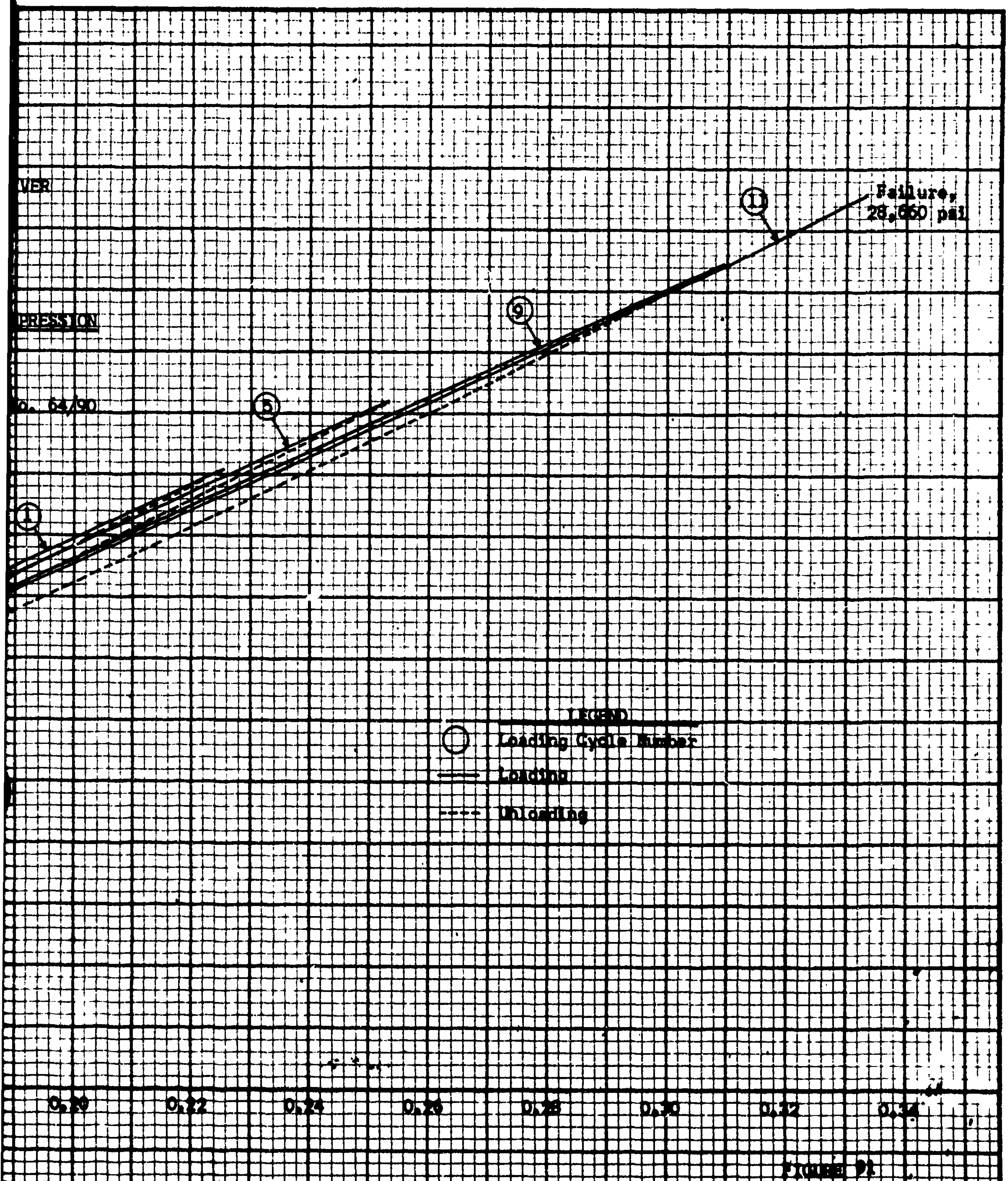
U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

CYCLIC LOADING OF ROCK CORE IN UNCONFINED COMPRESSION

PILEDRIVER

Core No. 47 MRD Lab. No. 64/90





VER
PRESSION
o. 64/90
Failure, 28,660 psi
1
5
9
11
LEGEND
Loading Cycle Number
Loading
Unloading
0.20
0.22
0.24
0.26
0.28
0.30
0.32
0.34

FIGURE 91

C

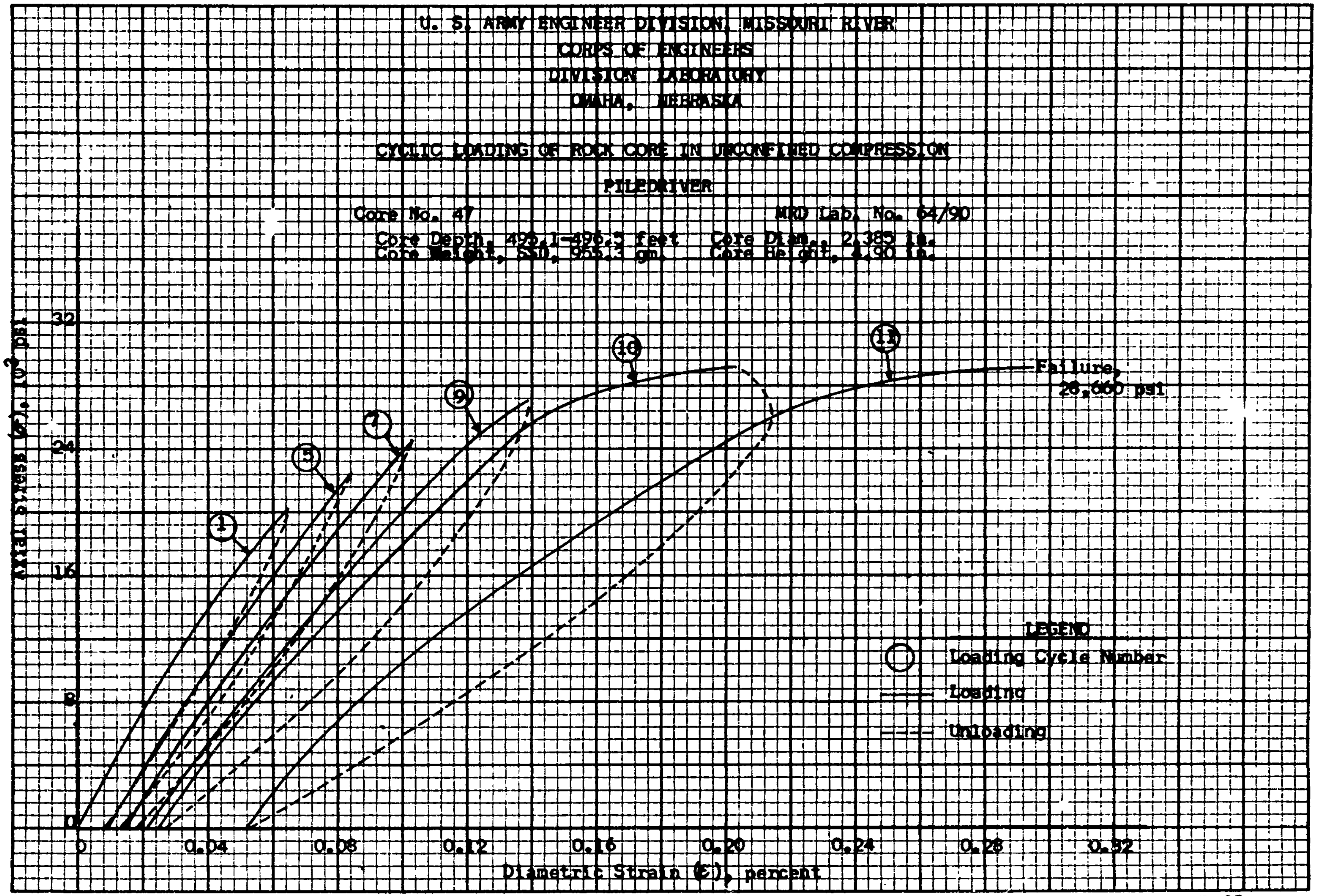
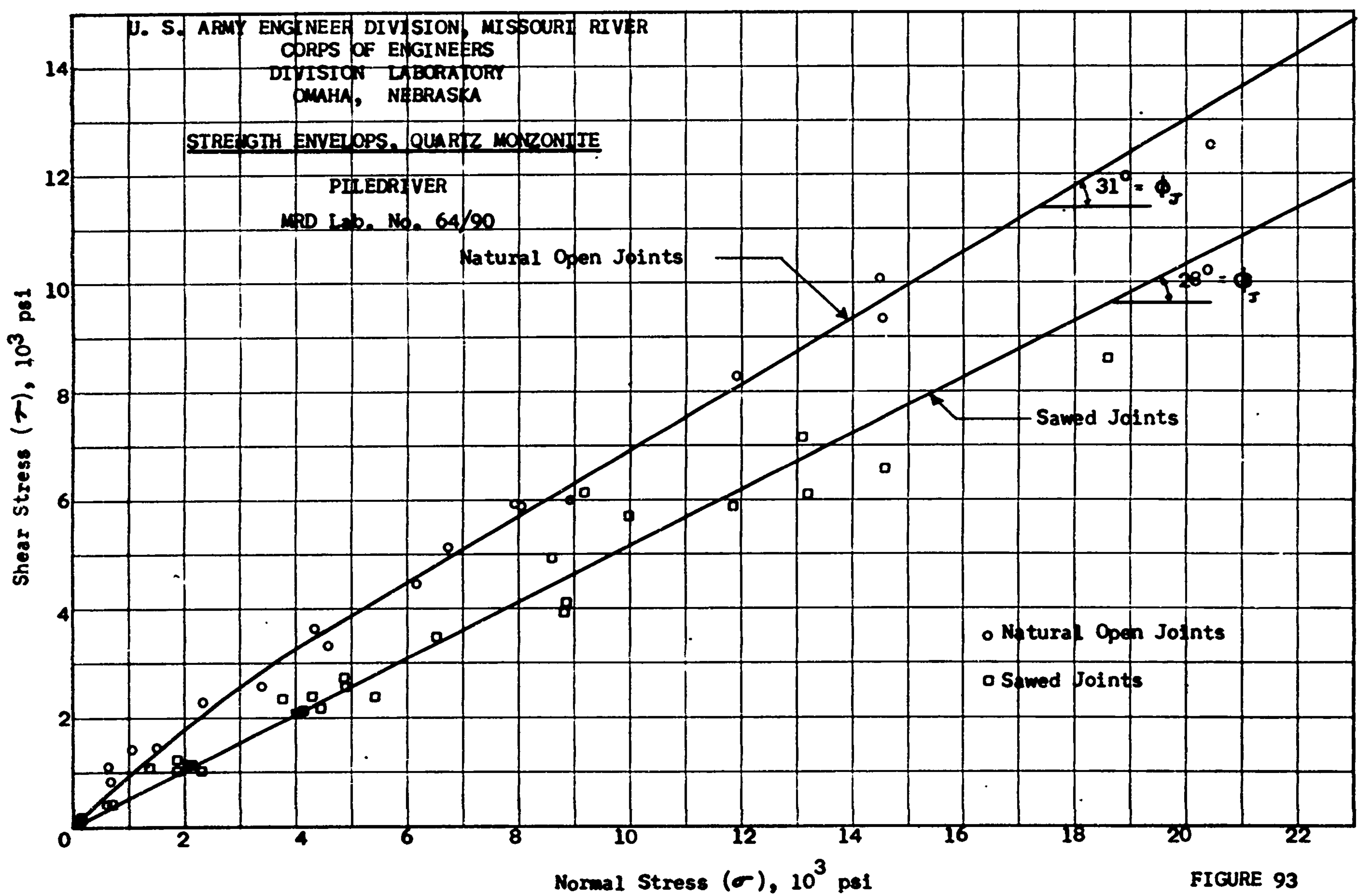
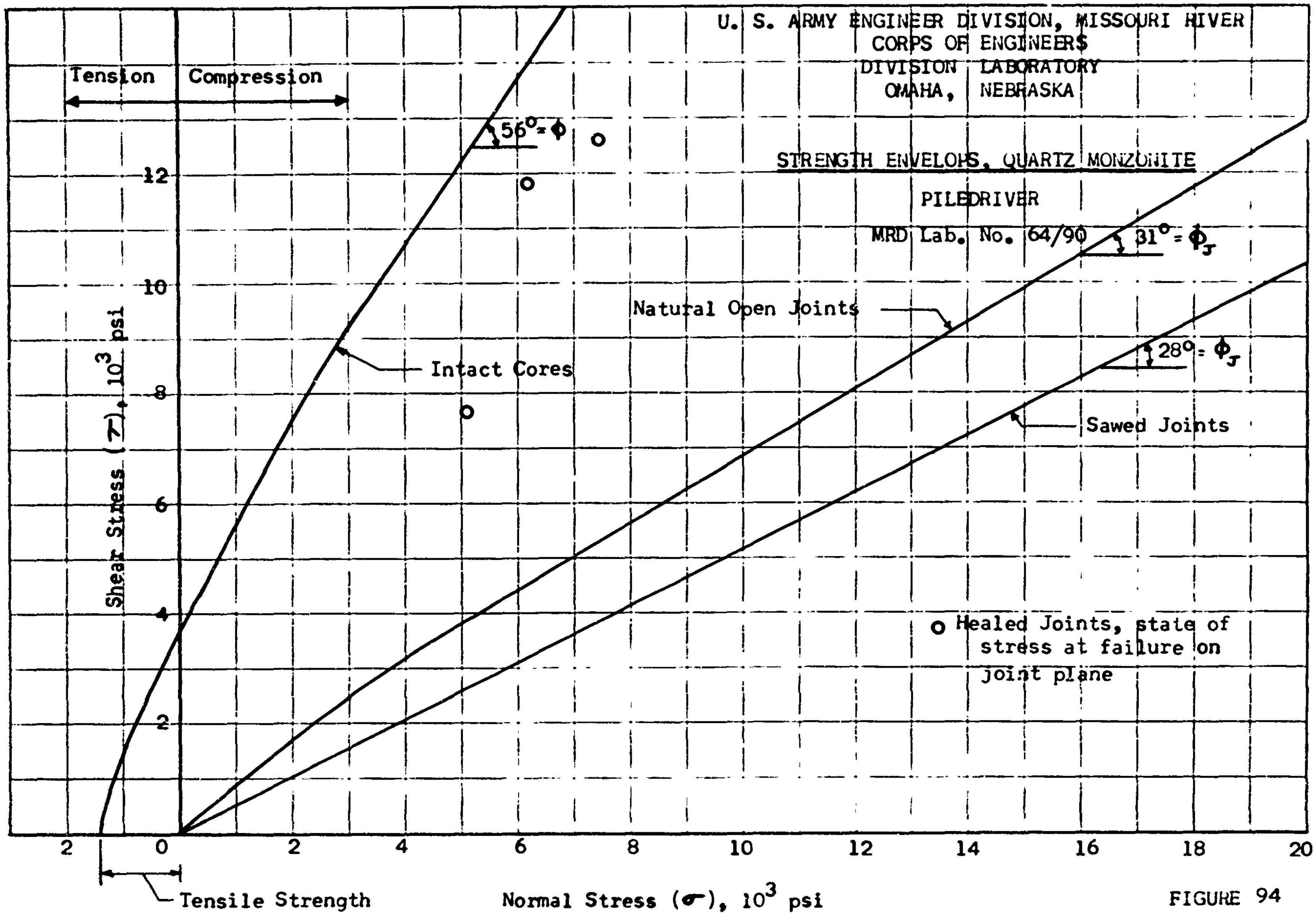

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA
CYCLIC LOADING OF ROCK CORE IN UNCONFINED COMPRESSION
PILEDRIVER
Core No. 47
MRD Lab. No. 64/90
Core Depth, 495.1-496.5 feet
Core Diam., 2.385 in.
Core Weight, SSD, 955.3 gm.
Core Height, 4.90 in.
1
5
7
9
10
11
Failure, 26,660 psi
LEGEND
Loading Cycle Number
Loading
Unloading
0
8
16
24
32
Axial Stress (σ), 10³ psi
0
0.04
0.08
0.12
0.16
0.20
0.24
0.28
0.32
Diametric Strain (ε), percent

FIGURE 92



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA
STRENGTH ENVELOPS, QUARTZ MONZONITE
PILEDRIVER
MRD Lab. No. 64/90
Natural Open Joints
Sawed Joints
31° = ϕ_J
28° = ϕ_J
o Natural Open Joints
□ Sawed Joints
Shear Stress (τ), 10^3 psi
Normal Stress (σ), 10^3 psi
0
2
4
6
8
10
12
14
16
18
20
22

FIGURE 93



U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA
STRENGTH ENVELOPS, QUARTZ MONZONITE
PILEDRIVER
MRD Lab. No. 64/90
Tension
Compression
56° = Φ
31° = ϕ_J
28° = ϕ_J
Intact Cores
Natural Open Joints
Sawed Joints
o Healed Joints, state of stress at failure on joint plane
Shear Stress (τ), 10^3 psi
12
10
8
6
4
2
2
0
2
4
6
8
10
12
14
16
18
20
Tensile Strength
Normal Stress (σ), 10^3 psi

FIGURE 94

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TABLE 1. -- SPECIFIC GRAVITY, DENSITY, AND POROSITY OF ROCK

Piledriver — MRD Lab. No. 64/90

	Core No.	Specific Gravity, Bulk SSD.	Measured Bulk Dry Density, gm./cu. cm..	Porosity
Triaxial Compression Test Specimens - Intact Rock	37	2.67	2.65	0.19
	133	2.67	2.64	0.24
	144	2.67	2.67	0.31
	40	2.68	2.66	0.30
	46	2.67	2.65	0.35
	69	2.70	2.68	0.21
	28	2.69	2.67	0.35
	83	2.67	2.67	0.19
	136	2.67	2.65	0.32
Triaxial Compression Test Specimens - Natural Healed Joints	130	2.67	2.66	0.35
	105	2.67	2.67	0.22
	142	2.66	2.65	0.35
	143	2.66	2.65	0.35
	131	2.67	2.66	0.35
	151	2.69	2.68	0.21
	138	2.67	2.66	0.19
	159	2.69	2.67	0.16
	155	-	-	-
	134	2.67	2.66	0.26
	153	2.70	2.67	0.20
Triaxial Compression Test Specimens - Natural Open Joints	120	2.68	2.63	0.20
	127	2.68	2.67	0.15
	158	2.66	2.63	0.33
	108	2.66	2.63	0.22
	125	2.67	2.67	0.22
	169	2.69	2.68	0.21
	107	2.66	2.63	0.22
	164	2.68	2.67	0.69
	112	2.69	2.64	0.24
	159	2.69	2.67	0.16
Triaxial Compression Test Specimens - Sawed Joints	23	2.69	2.65	0.22
	22	2.69	2.65	0.22
	11	2.67	2.64	0.23
	12	2.67	2.64	0.23
	18	2.70	2.67	0.21
	27	2.68	2.65	0.25
	128	-	-	-
	129	2.67	2.65	0.22
	35	2.68	2.65	0.20

Table 1

	Core No.	Specific Gravity, Bulk SSD.	Measured Bulk Dry Density, gm./cu. cm..	Porosity
Unconfined Compression Test Specimens - Intact Rock	39	2.67	2.67	0.22
	86	2.67	2.65	0.23
	132	2.68	2.64	0.40
Unconfined Compression Test Specimens - Natural Healed Joints	150	2.69	2.68	0.21
	137	-	-	-
Direct Tension Test Specimens - Intact Rock	9	-	-	-
	88	2.68	2.65	0.29
	126	2.67	2.67	0.22
Direct Tension Test Specimens - Natural Healed Joints	30	2.68	2.67	0.36
	43	2.67	2.65	0.18
	145	2.68	2.64	0.31
	54	2.68	2.66	0.20
Cyclic Loading Unconfined Compression Test Specimen - Intact Rock	47	2.67	2.65	0.35

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TABLE 2. -- CYCLIC LOADING OF ROCK CORE IN UNCONFINED COMPRESSION

PILEDRIVER

Core No. 47 MRD Lab. No. 64/90

Stress, ksi.	Axial Strain for Indicated Loading Cycle, micro-inches/inch.										
	1	2	3	4	5	6	7	8	9	10	11
0	0	+ 45	+ 65	+ 45	+ 50	+ 55	+ 55	+ 60	+ 62	+ 74	+ 118
1.120	- 135	- 100	- 85	- 155	- 85	- 83	- 81	- 70	- 79	- 75	- 45
2.239	- 255	- 228	- 220	- 227	- 220	- 225	- 230	- 212	- 230	- 230	- 205
4.478	- 520	- 505	- 442	- 510	- 500	- 506	- 512	- 502	- 515	- 520	- 497
6.717	- 765	- 785	- 757	- 766	- 770	- 770	- 781	- 770	- 795	- 798	- 779
8.957	-1007	-1030	-1010	-1020	-1022	-1028	-1035	-1030	-1060	-1065	- 1040
11.196	-1247	-1279	-1263	-1290	-1272	-1280	-1290	-1290	-1315	-1320	- 1310
13.435	-1500	-1545	-1520	-1550	-1535	-1545	-1554	-1558	-1585	-1590	- 1580
15.674	-1750	-1780	-1770	-1793	-1780	-1795	-1800	-1815	-1835	-1850	- 1839
17.913	-2000	-2020	-2016	-2040	-2028	-2045	-2055	-2060	-2085	-2100	- 2095
20.152	-2255	-2280	-2260	-2285	-2280	-2285	-2300	-2306	-2355	-2350	- 2342
22.391				-2535	-2531	-2540	-2555	-2560	-2590	-2600	- 2605
24.631						-2795	-2805	-2809	-2840	-2860	- 2855
26.870								-3070	-3095	-3107	- 3100
29.109										-3355	- 3336
28.660											Failure
26.870										-3120	
24.631								-2845	-2870	-2895	
22.391						-2565	-2555	-2618	-2640	-2655	
20.152				-2305	-2295	-2335	-2340	-2376	-2400	-2410	
17.913	-2030	-2040	-2035	-2075	-2073	-2105	-2110	-2139	-2165	-2166	
15.674	-1795	-1820	-1805	-1840	-1837	-1865	-1870	-1895	-1916	-1920	
13.435	-1555	-1580	-1560	-1595	-1591	-1615	-1626	-1646	-1665	-1664	
11.196	-1310	-1332	-1315	-1342	-1343	-1360	-1365	-1380	-1400	-1400	
8.957	-1063	-1080	-1060	-1090	-1086	-1095	-1100	-1096	-1128	-1115	
6.717	- 805	- 826	- 805	- 830	- 815	- 833	- 838	- 845	- 858	- 845	
4.478	- 540	- 559	- 535	- 560	- 545	- 555	- 555	- 560	- 570	- 556	
2.239	- 257	- 265	- 245	- 267	- 250	- 260	- 250	- 250	- 260	- 236	
1.120	- 110	- 115	- 95	- 115	- 95	- 101	- 95	- 90	- 100	- 70	
0	+ 45	+ 32	+ 60	+ 55	+ 60	+ 59	+ 65	+ 75	+ 65	+ 105	

Note: Negative values indicate strain gage compression, positive values indicate strain gage tension.

See Figure 91 for stress-strain curve.

U. S. ARMY ENGINEER DIVISION, MISSOURI RIVER
CORPS OF ENGINEERS
DIVISION LABORATORY
OMAHA, NEBRASKA

TABLE 3. -- CYCLIC LOADING OF ROCK CORE IN UNCONFINED COMPRESSION

PILEDRIVER

Core No. 47 MRD Lab. No. 64/90

Stress, ksi.	Diametric Strain for Indicated Loading Cycle, micro-inches/inch.										
	1	2	3	4	5	6	7	8	9	10	11
0	0	60	78	85	100	120	144	163	222	251	522
1.120	35	99	121	127	137	154	179	197	255	289	556
2.239	62	127	150	148	169	187	214	230	291	326	595
4.478	121	191	219	217	237	257	288	305	370	408	689
6.717	180	260	286	287	310	328	362	382	452	497	796
8.957	242	327	351	357	377	403	439	461	540	590	914
11.196	310	393	420	432	451	474	517	543	629	689	1046
13.435	389	468	492	506	528	554	603	630	725	796	1194
15.674	465	539	565	578	601	629	681	711	820	898	1343
17.913	553	610	639	656	677	705	765	794	913	1004	1496
20.152	652	690	715	728	754	784	849	880	1011	1107	1646
22.391				817	842	864	934	969	1109	1219	1819
24.631						980	1030	1060	1218	1340	2005
26.870								1242	1390	1510	2244
29.109										2029	2946
28.660											Failure
26.870										2130	
24.631								1230	1365	2112	
22.391						942	989	1169	1300	2020	
20.152				776	792	889	931	1099	1226	1917	
17.913	612	648	670	717	733	827	867	1025	1145	1806	
15.674	561	590	611	656	676	765	799	952	1061	1687	
13.435	503	530	551	594	611	694	724	869	977	1554	
11.196	439	466	488	522	541	616	642	775	872	1405	
8.957	374	399	419	453	466	536	560	675	766	1244	
6.717	308	325	347	377	391	454	473	576	653	1080	
4.478	237	250	271	297	308	365	381	468	531	901	
2.239	160	170	190	215	223	270	283	351	406	718	
1.120	121	132	150	171	179	223	236	291	341	627	
0	81	93	110	135	139	175	188	238	280	538	

Note: All strain values are positive, indicating strain gage tension.

See Figure 92 for stress-strain curve.